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ELECTRICITY IN THE OLD NAVY.

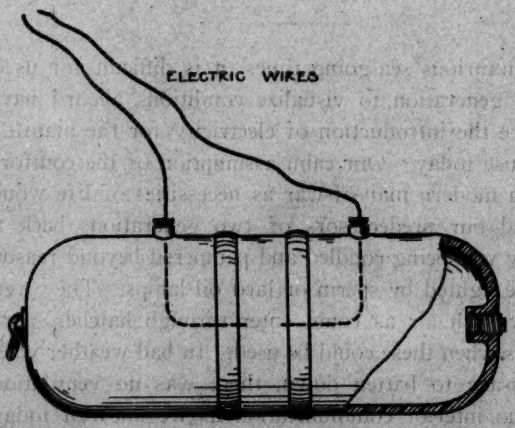
By Lieut.-Comdr. A. M. Charlton, U. S. Navy, Member.

In these luxurious sea-going times, it is difficult for us of the younger generation to visualize conditions aboard naval vessels before the introduction of electricity for the manifold purposes in use today. Our calm assumption of the comforts enjoyed on a modern man-of-war as necessities of life would certainly lead our predecessors of two generations back to say the Navy was being coddled and pampered beyond reason.

Ships were lighted by sperm or lard oil lamps. They were ventilated by such air as could enter through hatches, ports and windsails when these could be used. In bad weather when it was necessary to batten down, there was no ventilation. There was no interior communication as we know it today. Much of the work done by electric motors today was hand labor then.

But electricity was experimented with, and used for various purposes, in these early times. It is the purpose of this article to show how electricity was employed in the Navy from the earliest days until 1883, when the lighting plant of the U. S. S. *Trenton* was installed.

The earliest use of electricity in the Navy which the author has found was the explosion of a submarine mine off Castle Garden, New York (The Battery) from the U. S. S. *North Carolina* on the 4th of July, 1842. Mr. Samuel Colt, the inventor of the revolver, and Mr. Samuel Morse, the inventor of the telegraph, made the experiment. An old gunboat brought down from Lake Champlain was filled with rubbish and towed away from the ship's side by a small boat. At a distance of three hundred yards from the *North Carolina*, the battery circuit was completed and the gunboat was thrown high in the air, much to the astonishment and delight of the crowd assembled on the Battery.



CONFEDERATE MINE 1864

FIG. 1.

Electrical submarine mines were employed by both the Federal and Confederate Navies during the Civil War. The Confederates were successful in several instances with this type of mine, among them being the damage of the *Commodore Barney* in 1863 and the destruction of the *Commodore Jones.* In each case a mine containing 1,750 pounds of powder was used. The Federals were entirely unsuccessful with electric mines. These mines were made of copper, cast iron, rubber, wood and tin, using various amounts of powder and fired from batteries through wire insulated with india rubber or gutta percha and hemp. Fig. 1 shows a confederate torpedo picked up by the Potomac Flotilla under Commander Parker in 1864. It was three feet long and seventeen and a half inches in diameter, made of sheet copper and contained two hundred and fifty pounds of powder.

Undoubtedly electric bells were used to some extent before 1870, for in the report of the Chief of the Bureau of Navigation dated October 20, 1869, is found this item in the estimate of expenditures for the year ending June 30, 1871:

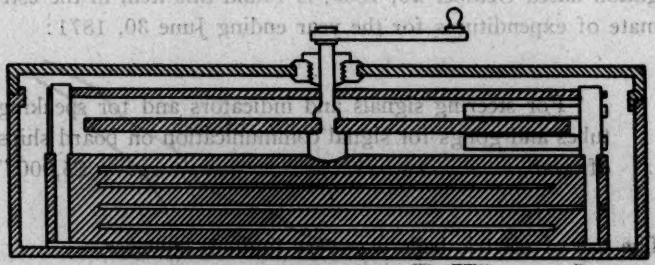
"For steering signals and indicators and for speaking tubes and gongs for signal communication on board ships of war.....$5,000."

The use of electric bells was very limited, however.

Previous to this time until the Torpedo School was established at Newport in 1869, electricity was a closed book to most of the service. The importance of the torpedo as an offensive weapon became a very live subject and with its use came a need for electrical knowledge. It may be said here that the term 'torpedo' was applied to any explosive charge whether carried on an out-rigger spar or towed astern of a man-of-war, submerged in a harbor or carried on a small boat known as a torpedo boat.

Twenty officers were sent each year to Newport for torpedo instruction. The course in electricity embraced lectures on batteries of various kinds, Ohm's law, methods of arranging batteries, electric arc lights, magnets and magnetism, and various electrical machines for generating voltage. These lectures were supplemented by a course of practical work which prepared the students to operate and maintain the electrical equipment necessary for firing torpedoes. Working with electricity in connection with torpedoes naturally led the personnel of the Torpedo Station to experiment with its use for other purposes.

The use of electricity for firing torpedoes as opposed to contact detonators was made mandatory by the desire to place the firing apparatus under control, thus rendering the torpedoes safer to friends and easier to handle. By 1874, electricity was almost exclusively employed as a firing agent.



SMITH'S FRICTIONAL MACHINE 1870

FIG. 2.

Three types of apparatus were employed to obtain firing current: frictional machines, galvanic batteries and induction machines.

Smith's frictional machine (Fig. 2) consisted of a circular ebonite plate (the generator), which was revolved by a crank

between two pieces of sheet brass (the rubbers) covered with thick flannel over which was sewn oiled silk. Two small brass collectors were placed one over and one under the generator. A condenser of alternate plates of ebony and tinfoil was placed below the generator and rubbers. The alternate tinfoil plates of the condenser were connected to the rubbers and collectors. When the generator plate was turned, the condenser was charged and when the circuit to the fuse was closed, the condenser discharged. This type of machine was never issued generally to the service as experiments proved that the fuse required was extremely sensitive and dangerous, could not be stored for any length of time, and finally it had such high resistance that any ground in the system rendered firing impossible.

Many types of batteries were tested at the Torpedo Station and countless experiments made to determine their characteristics. Among the types experimented with, the following were the most used:

Daniell's Battery consisted of a zinc plate in a solution of zinc sulphate or sulphuric acid and a copper plate in a saturated solution of copper sulphate. The battery with proper care would give a constant current for months. The E. M. F. of the cell was about .98 volts and the current obtained ranged from .1 to .25 ampères, depending on the size of the cell.

The *Gravity Battery* was a modification of the Daniell. In the bottom of a glass jar was a copper plate surrounded by crystals of copper sulphate; to the copper plate was soldered an insulated wire which led to the top of the jar. In the top of the jar, which was filled with water, an annular zinc plate was suspended. The E. M. F. was 1 volt and the current varied from .4 to .7 ampères.

The *Le Clanché Battery* consisted of a glass jar and a porous cup glazed for half its length. In the porous cup was placed a carbon plate surrounded by gas carbon and manganese peroxide. The top of the porous cup was sealed with

pitch. The glass jar contained a zinc rod and was half filled with a weak solution of sal ammoniac. The E. M. F. was about 1.5 volts and the current was half an ampère. This type of battery polarized rapidly and so was not used for constant service. For intermittent service such as bells or signals, it would last for nearly a year without changing the constituents.

The *Station Battery* was much used. It consisted of a zinc plate in dilute sulphuric acid and a carbon plate in a mixture of nitric acid and a solution of bi-chromate of potash, the latter being in a porous cup. This battery stood up very well. Its E. M. F. was about 2 volts and the current varied from 4 ampères when first set up to 2 ampères at the end of two weeks.

These batteries were all wet cell primary batteries. There was no ampère hour rating established, the usual designation being "quart" or "half-gallon" size.

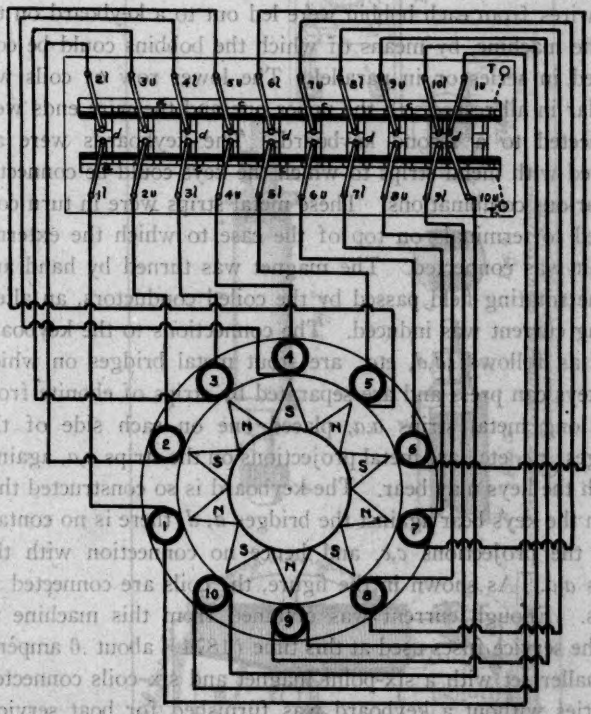
In torpedo work the batteries were used for three purposes; signalling, testing and firing.

For signalling and testing, a weak current which would not fire a fuse was required and for firing, a large current was necessary. For this reason it was specified that for signalling and testing, the battery cells should always be put in series. The fuse issued to the service at this time (1874-75) took about .6 ampère to fire it. For testing and signalling, the Daniell, Gravity or Le Clanché cell was used, and for firing, the Station battery was employed, although in the *Trenton's* installation in 1877 (described below), Le Clanché cells were used for both purposes.

It is interesting to note that at this time the unit of quantity of electricity was called the *farad* and the ampère was called the *weber*. This was before the date of the International Congress in 1882, which designated the nomenclature in use today.

Two types of induction machines were used: magneto-electric machines using permanent magnetism for field excitation and dynamo-electric machines using generated current for the field.

Beardslee's Magneto-Electric Machine (Fig. 3) consisted

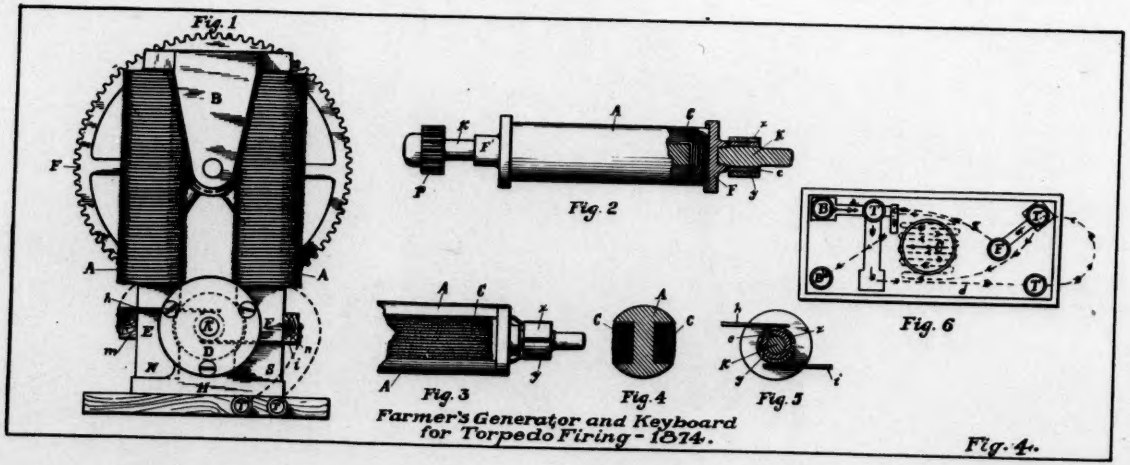


BEARDSLEY'S MAGNETO-ELECTRIC MACHINE
FIG. 3.

of a star-shaped compound magnet of hard iron with ten points alternating in polarity which revolved between two horizontal rows of bobbins, one placed over and one under

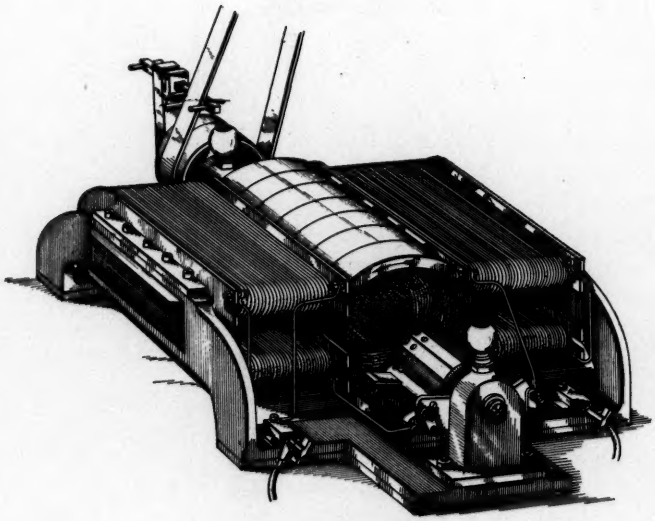
the magnets. The bobbins had soft iron cores and each was wound with 1,320 feet of fine silk-covered copper wire (No. 23 B. G.). The bobbins were secured to two large iron rings, ten to each ring, the distance between the centers of the bobbins being equal to that between the points of the magnets. The upper row of bobbins was all wound in one direction and the wires from each bobbin were led out to a keyboard on top of the machine, by means of which the bobbins could be connected in series or in parallel. The lower row of coils was similar in all respects to the upper one and the wire ends were connected to a second keyboard. The keyboards were arranged with metal strips to which the keys could be connected in various combinations. These metal strips were in turn connected to terminals on top of the case to which the external circuit was connected. The magnet was turned by hand and as the rotating field passed by the coiled conductors, an alternating current was induced. The connections to the keyboard were as follows: *d,d,* etc., are stout metal bridges on which the keys can press and are separated by strips of ebonite from two long metal strips *a,a,* placed one on each side of the bridges; *c,c,* etc., are metal projections on the strips *a,a,* against which the keys may bear. The keyboard is so constructed that when the keys bear against the bridges *d, d,* there is no contact with the projections *c,c,* and hence no connection with the strips *a,a.* As shown in the figure, the coils are connected in series. Enough current was obtained from this machine to fire the service fuses used at this time (1874), about .6 ampère. A smaller set with a six-point magnet and six coils connected in series without a keyboard was furnished for boat service.

A small induction machine known as Breuget's was at one time issued to the service but the power obtained was so small that there was great uncertainty in firing fuses and its use was abandoned. Its action was as follows: moving the armature away from a horse-shoe magnet changed the intensity of the field which induced current in the coils wound on each



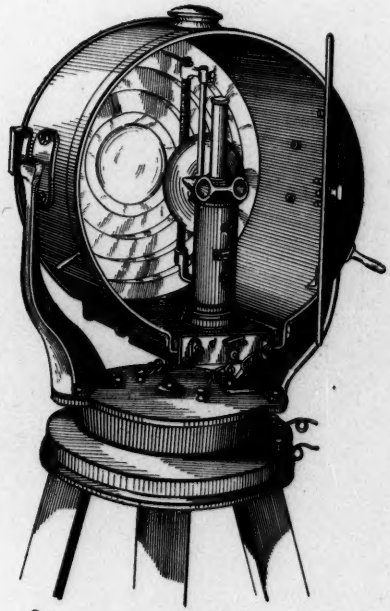
Farmer's Generator and Keyboard for Torpedo Firing - 1874.

Fig. 4.

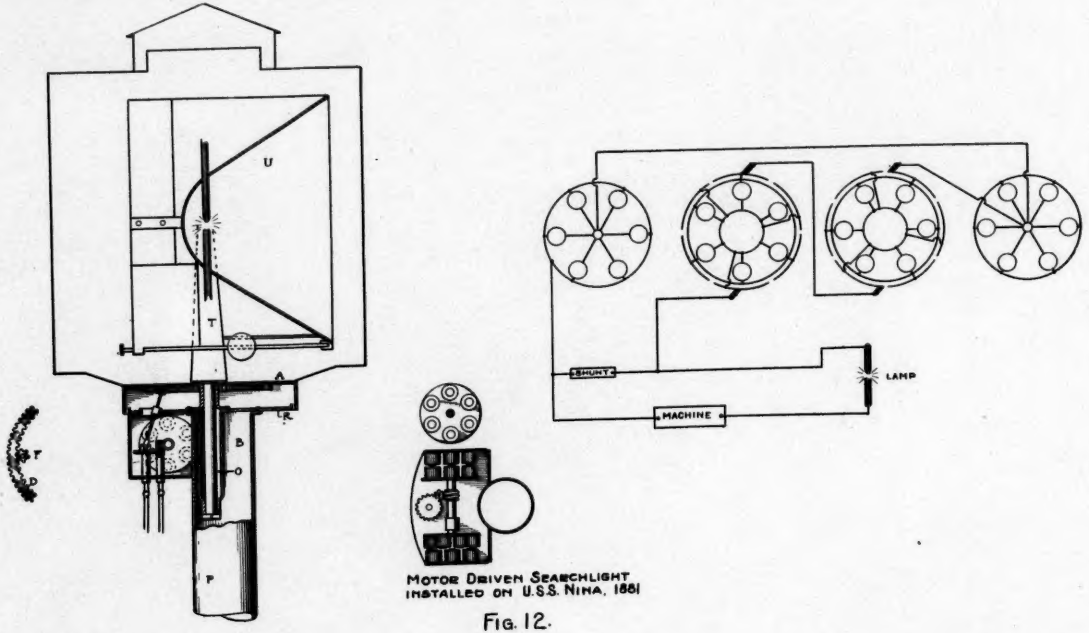


SIEMENS' DYNAMO

FIG. 8.



SIEMENS' SEARCHLIGHT
FIG. 10.



MOTOR DRIVEN SEARCHLIGHT
INSTALLED ON U.S.S. NINA, 1881

FIG. 12.

pole of the magnet. The movement of the lever which brought the armature away from the magnet also connected the coils to the external circuit. A condenser was put across the coils and its discharge, when the lever was pressed, assisted in firing the fuse.

In 1875, the machine issued to all vessels of the Navy for firing torpedoes was Farmer's dynamo-electric machine. Professor Moses Farmer was attached to the Torpedo Station and was known at that time as a rather eminent electrician. His machine (Fig. 4) was a bi-polar, series-wound, direct current generator operated by hand. The voltage obtained was about 16 and due to the high resistance of the armature (5 ohms), only a little over 3 ampères was obtained on short circuit. The machine consisted of the electro-magnets, the armature and the commutator. The field cores were two slabs of soft cast-iron E,E, and the field coils A,A, were of coarse silk-covered wire. The slabs E,E were scored out at their lower ends to surround the armature. They were secured at the top by an iron plate B, which carried two lugs for the bearings of the cog-wheel axle, and at the bottom were bolted to a composition bedplate H. This plate had two lugs D, which formed the bearings for the axles K of the armature A. The armature was of the best quality of soft wrought iron, in which longitudinal scores were cut. In each of these scores a number of turns of fine silk wire were wound to form the armature coil C. To each end of the armature were bolted brass discs F and F′, which carried the axles K. On the rear axle was secured a brass pinion P, which geared into the cogwheel F and served to communicate motion to the armature when the crank was turned.

The commutator consisted of a cylinder of ebonite or ivory secured to the axle. To this cylinder were secured semi-cylindrical copper shells insulated from each other by the ebonite. On the commutator pressed two brass springs (brushes) which

were secured to the insulating brackets *m* and *n*. The whole machine was placed in a metal-strapped hardwood box and as issued to the service, weighed 116 pounds.

A firing key was used, arranged so that the E. M. F. could be built up to its maximum as rapidly as possible by putting a low resistance (.01 ohm) across the terminals. The keyboard also permitted the introduction of a large resistance (200 ohms) into the external circuit so that sufficient current could be obtained to test the circuit without firing the fuses. A compass needle used with this coil showed a deflection when the circuit was complete.

Referring to the figure, when no keys were pressed, the current flowed from the machine to B, *a*, *c*, B′ and back to the machine. For testing, T was pressed which broke the connection between *a* and *c*, and the current flowed to B, *a*, along *d*, to T′, out to the fuse, back to T″ through coil C to *c*, B′ and back to the machine.

For firing, T and F were both pressed so that most of the current coming from T″ passed through the low resistance *g* and very little through C, enough going through the latter, however, to deflect the compass needle.

The resistance of the fuse was about 1 ohm and the resistance of the leading wires to the fuse was also taken as 1 ohm (equivalent to 350 feet of No. 14 wire).

$$\text{On short circuit the current} = \frac{16}{5+.01} = 3.19 \text{ amps.}$$

$$\text{For testing, the current} = \frac{16}{5+1+1+200} = .077 \text{ amps.}$$

$$\text{For firing, the current} = \frac{16}{5+1+1+\frac{200\times.01}{200\times.01}} = 2.26 \text{ amps.}$$

In a lecture by Lieut. John P. Merrell, U. S. Navy, at Newport in 1875, from which the above description of Farmer's machine is taken, the following advantages of this type of machine are given:

"Farmer's machine seems to be peculiarly adapted for use in offensive torpedo operations.

"I. It has abundant power. When turned by hand it can be depended upon to fire a fuse through a resistance of twenty ohms (equivalent to 8,000 feet of Siemens' cable) provided the insulation is good.

"II. When intelligently handled its action is certain; at least as certain as any mechanism can be expected to be.

"III. By means of the firing key, the continuity of the circuit can be tested at any time.

"VI. It is not at all affected by changes in climate.

"VII. It will fire through poor insulation. Nearly all the large machines so far issued have fired through 600 feet of No. 14 B. G. naked copper wire submerged in sea water * * * an amount of faulty insulation not likely to be encountered in practice.

"VIII. The machine can be placed at any part of the ship desired and the firing key taken to the bridge or station of the officer operating the vessel, thus placing the control of the fire immediately in his hands."

Early in 1874, the North Atlantic Fleet held torpedo exercises off Key West, Florida. Twenty-five vessels were present and fourteen fired torpedoes during the exercises. The target consisted of seventy-eight barrels secured to a light wooden framework and arranged in three tiers. The upper tier contained forty barrels, ten by four; the second, twenty-four, eight by three; and the lower, fourteen, seven by two. The bungs of the two lower tiers were left out so that the barrels might fill with water, but at most the target drew but four and a half feet of water. As the torpedoes

were submerged to a depth of twelve feet, the target was little more than a point of aim, no explosive effect being obtained.

The target was set adrift and the vessels approached it in column open order, the *Wabash* leading, followed by the *Congress, Ticonderoga, Canandaigua, Ossipee, Colorado, Brooklyn, Wachusett, Kansas, Lancaster, Franklin, Alaska, Shenandoah,* and *Fortune.* The speed of the vessels was four to five knots, except the *Franklin* two to three knots and the *Fortune* about ten. The wind was very light and the water smooth, without sea or swell.

All torpedo spars were rigged on the starboard side. These spars varied in length from forty to sixty feet, and carried torpedoes which contained from seventy-five to one hundred and ten pounds of powder, usually in a cylindrical case. Some of the vessels fired their torpedoes by battery, and others with Farmer's dynamo-electric machine or Smith's frictional machine. Eighteen torpedoes were intended to be fired on this practice, but seven failed to explode for various reasons. No damage was done to the firing vessels except to some of the torpedo spars.

It seems rather ludicrous to us today that vessels should seriously consider the possibility of maneuvering within fifty feet of an enemy, dragging a submerged forty-foot spar with its attached mine, but when it is considered that "great gun" practice was held at this same time at 600 and 1,000 yards, it does not seem so impossible to get alongside an enemy without annihilation. It was hoped too that occasions might arise where the enemy would be come upon at night or when anchored, so that a torpedo could be fired more advantageously.

The practice served at least to give officers an idea of torpedo firing, which many of them had not witnessed before, and to reassure them of the safety of one's own vessel when the torpedo was exploded at the end of the spar.

The following description of the wiring system for firing torpedoes installed on the *Intrepid* in the early part of 1876 is taken from a report by Lieutenant-Commander Royal B. Bradford, U. S. N., who supervised the installation and did much of the work himself:

"* * * The wooden deck of the *Intrepid* being only from 2½ to 3 feet above the water line and the fact that this deck is covered with water at sea, renders it impracticable that any connection between permanent wires and spar leading wires should occur above the deck. Besides this, I considered that it was very important to have the permanent wires protected by the armor of the ship and below the water line when possible; also that as little wire should be exposed as practicable. Accordingly 1¼-inch holes were bored through both decks (the distance from the top of the wooden deck to the bottom of the iron one being 17 inches) as near as practicable to the heel of the spars. In these holes were placed iron pipes, made watertight through the deck, connected with a brass casting on top, the latter being constructed so as to receive a rubber gland, packed with a brass cap. The two latter are such as used for fuse connections with cast iron torpedoes. The short spar wires pass down through these pipes, and connect below to the permanent wires. * * *

"I considered the best location for the exploding apparatus was in the pilot house, so that it, the wires connected with it, and the operator might be protected, particularly from the fire of rifles and Gatling guns.

"For these reasons the apparatus was placed in the pilot house and this of course necessitated all permanent wires being led from there. Having long been an advocate of voltaic batteries for torpedo work, one was recommended for the *Intrepid*, and besides being approved by you, was subsequently specially ordered by the Bureau of Ordnance.

"The ordnance storeroom in the after end of the ship seemed the best adapted for the storage of this battery; and here a shelf was utilized for that purpose by simply placing another shelf above it with holes cut after the manner of an ordinary tumbler rack on board ship. The battery placed here consisted of 48 Le Clanché cells connected four for quantity or conductivity and twelve for intensity or in series. Two spare cells were also furnished. * * * It was not deemed advisable to dispense with Farmer's machine, since the use of voltaic batteries is, as yet, but an experiment. It was thought that the best place for the machine would be on the berth deck immediately under the pilot house where it and the operator would be entirely protected and where the operator could be easily spoken to from the pilot house.

"The *Intrepid* had two torpedo spars * * * as the *Intrepid* is fitted to carry four torpedo spars, two were furnished from this station.

"From what has been said, it will be seen that it was necessary to run nine permanent wires from the pilot house to different places in the ship, as follows, viz: Two to voltaic battery in ordnance storeroom, two to terminal binding screws on berth deck for Farmer's machine, four to terminal binding screws abreast of torpedo spars for spar leading connections, and one to a permanent earth. How to run these wires was a difficult matter to decide. The whole of the inside of the ship is of iron and great care must be exercised to prevent chafe of insulation, for if a naked wire touches the ship an earth is formed at once. * * * Along the inside of the ship's frame, nearly down to the bottom of the boilers, runs fore and aft an iron girder, and it was decided to run the four wires going aft through lead pipe and secure this pipe to the girder. This was done, the lead pipe extending as far aft as the starboard after spar terminal. From here one wire crossed the deck, protected by an iron beam, to the port after

spar terminal, and two more wires continued aft to the ordnance storeroom to connect with the voltaic battery. The after part of the ship being lined with wood, these wires were stapled to it and covered with tin gutters or scotchmen. These last three wires were covered with an extra linen thread braiding, rubbed down with a paraffine mixture and varnished. A piece of this same lead pipe led from pilot house to berth deck forward to machine terminals, the other two wires continuing on to terminals for forward spar wires. One of these on the port side had to be protected from the galley by being led through lead pipe. The earth wire was run through a small lead pipe to a berth deck beam and connected to the latter by means of a brass binding screw. The permanent wires are connected to the spar wires in this manner: Small walnut shelves are secured to iron bulkheads with brackets, directly underneath the pipes in the deck. In the middle of these shelves is placed a brass binding screw, terminating on the bottom in a countersunk cavity. The permanent wires are connected to the binding screws in this cavity before the brackets are secured to the bulkheads, the insulation of the wire extending inside of it. After the connection was made, the cavity was filled with a melted waterproof compound that, when cold, was hard. In this way the connection was protected from rust and salt water as well as insulated. The terminals for Farmer's machine were arranged in the same manner.

"It remains now only to describe the testing and firing apparatus placed in the pilot house. The keyboard (Fig. 5) was placed on a shelf at a convenient height for working the keys and secured with dowels and buttons. * * * The wires connecting with the keyboard and their corresponding binding screws were similarly tallied, so that no mistake could be made in connecting and disconnecting them. The first time the keyboard was used, as well as afterward, it worked very satisfactorily indeed."

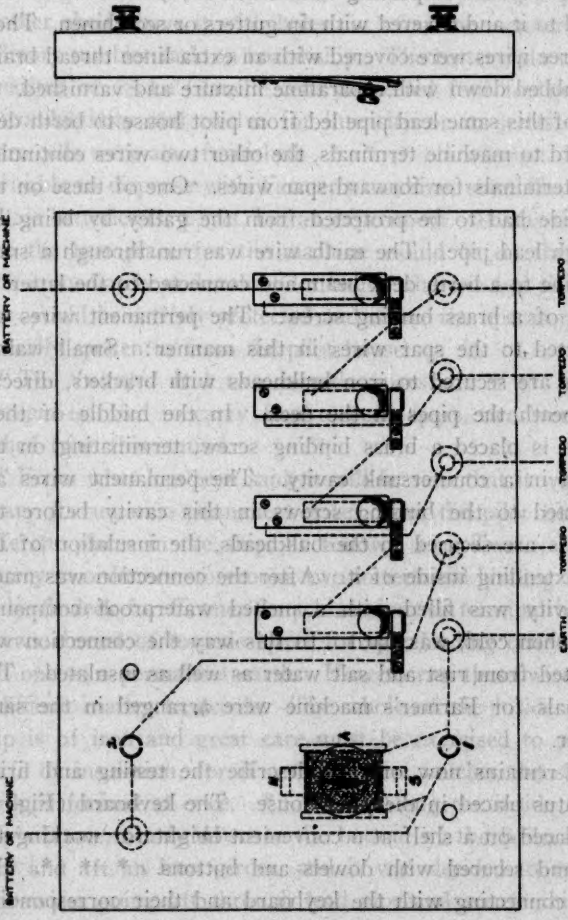

BATTERY OR MACHINE
TORPEDO
TORPEDO
TORPEDO
U.S.S. INTREPID. 1878.
TORPEDO
EARTH
TORPEDO FIRING KEYBOARD
BATTERY OR MACHINE

FIG. 5.

This keyboard was quite an improvement over those previously issued to the service. Before this keyboard was designed, only Farmer's machines could be used as no arrangements were made for using a battery. The testing coil on former boards had no permanent magnets N,S (see Fig. 5) to hold the compass needle, so that it was necessary to turn the board as the ship changed course, to keep the plane of the coil in the meridian. This was no easy task with several wires attached to the board.

DIRECTIONS FOR USING KEYBOARD.

If using battery, shunt plug 2 must be out at all times. If using machine, 2 must remain in.

To test firing circuit, take out shunt plug 1, press firing keys and note deflection of compass needle A, showing that circuit is complete. To fire, put in plug 1 and press firing key.

Fig. 6 shows a number of fuses used for firing torpedoes. The fuses for use with the various machines were the same in outward appearance, the difference being in the igniter.

For frictional machines, a sensitive compound in the igniter exploded when the disruptive discharge occurred, which in turn ignited the rifle powder of the fuse. The sensitive compound was composed of

Potassic chlorate.....	45.00 per cent.
Antimonious sulphide...	20.75 per cent.
Red phosphorous.....	5.75 per cent.
Carbon.....	28.50 per cent.

For magneto-electric machines, the break in the wire (not over .05 inch) was bridged with plumbago obtained by rubbing a soft lead pencil in the groove at A, (Fig. 3 of Fig. 6). The passage of the current heated the plumbago sufficiently to ignite the powder.

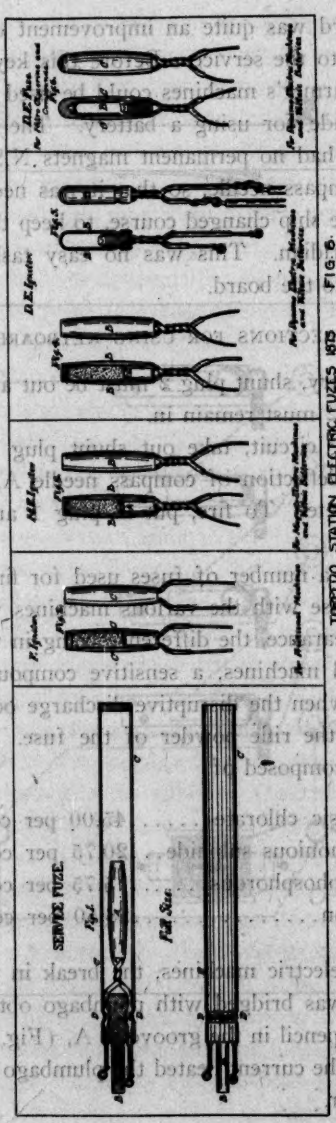

TORPEDO STATION ELECTRIC FUZES 1875
SERVICE FUZE
Full Size

FIG. 6.

For dynamo-electric machines and batteries, the break in the wire was bridged with a 3/16 inch piece of fine platinum wire. When the current passed, this wire was heated to incandescence and the powder was ignited.

These various types of igniters were all devised by Lieut. Bradford.

In 1877, a battery installation for firing torpedoes and guns, and for a call bell and fire alarm system, was installed on the U. S. S. *Trenton*.

The apparatus furnished was for two distinct purposes; first, firing guns and torpedoes; second, calls and automatic fire alarm.

That intended for guns and torpedoes was designed to place the firing under the control of a single officer stationed on the bridge, who was able to fire any gun or torpedo when it was ready. It was arranged to have the fact that a gun was ready signalled to the control officer by the gun-captain, who could throw out this signal if he were changing the point of aim. The gun-captain also had a signal at the gun to tell him if his circuit were complete and a switch under his control to open the firing circuit if for some reason the gun should not be fired. On the bridge was an instrument called the Annunciator, which in shape and size resembled a standard compass. Inside along the sides were two rows of four ports each, corresponding to the guns in broadside. At either end were two more ports corresponding to the bow and quarter torpedoes. Outside of the instrument, but protected by a brass shield, abreast each of the ports was a firing key. There was also a firing key for each broadside.

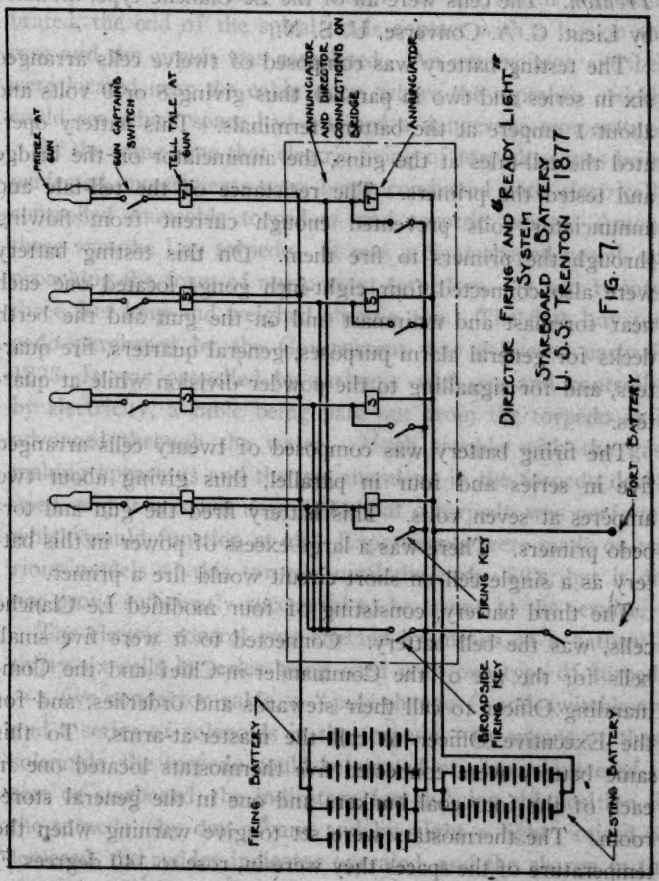
In the rear of each gun on the gun deck overhead, was an instrument called a "tell-tale" which showed when a current passed through the circuit to the gun. The two wires leading from the tell-tale were terminated in an instrument called the primer connection, which furnished a ready means of putting

the primer into the circuit. On one of the wires between the tell-tale and primer connection was a switch which was held by the gun-captain. When the primer was connected and the gun-captain's switch closed, the tell-tale, which was a galvanometer, revolved two red quadrants in a white field before the gun-captain's eyes. At the same time, a red signal bearing the number of the gun showed in the corresponding port in the annunciator on the bridge. There was sufficient resistance in this signalling circuit in the annunciator to prevent the primer being fired, but when the corresponding firing key was pressed, the firing battery was connected to the circuit and the primer fired.

The object of the tell-tale was to show the gun-captain that his circuit was complete, and at the same time he knew the bridge had been informed. It also took the place of the order "Ready" to the gun crew, as the tell-tale was in plain sight of them all. The tracks of the gun deck battery were marked for concentration of fire and a "Director" was made to ship on top of the annunciator so that the broadside could be concentrated and fired from the bridge.

We thus see director firing in use forty-three years ago. This was the first installation of this type in the U. S. Navy, and probably the first electric system in the world. The British had a director system as early as 1829, but electric firing was not used. The *Trenton's* system approached remarkably close to the system in use today considering the gear in use.

The guns were laid in elevation and trained so as to concentrate on one point of aim, the firing officer was notified when the guns were ready and the broadside could be fired in salvo from the bridge. Fig. 7 shows the electrical circuits for the starboard battery. The electrical circuits for the torpedoes were the same as those for the guns except that there were no tell-tales. As the connections were made on the spar deck in sight of the bridge, none were necessary.


DIRECTOR FIRING AND READY LIGHT SYSTEM
STARBOARD BATTERY
U. S. S. TRENTON 1877
FIG. 7.
ANNUNCIATOR AND DIRECTOR CONNECTIONS ON BRIDGE
ANNUNCIATOR
GUN CAPTAINS SWITCH
TELL TALE AT GUN
FIRE AT GUN
PORT BATTERY
FIRING KEY
BROADSIDE FIRING KEY
FIRING BATTERY
TESTING BATTERY

The spar deck guns could be fired electrically by using such of the torpedo circuits as were not in use.

There were three galvanic batteries in use on board the *Trenton*. The cells were all of the Le Clanché type, modified by Lieut. G. A. Converse, U. S. N.

The testing battery was composed of twelve cells arranged six in series and two in parallel, thus giving 8 or 9 volts and about 1 ampère at the battery terminals. This battery operated the tell-tales at the guns, the annunciator on the bridge and tested the primers. The resistance of the tell-tale and annunciator coils prevented enough current from flowing through the primers to fire them. On this testing battery were also connected four eight-inch gongs located one each near foremast and mainmast and on the gun and the berth decks for general alarm purposes, general quarters, fire quarters, and for signalling to the powder division while at quarters.

The firing battery was composed of twenty cells arranged five in series and four in parallel, thus giving about two ampères at seven volts. This battery fired the gun and torpedo primers. There was a large excess of power in this battery as a single cell on short circuit would fire a primer.

The third battery, consisting of four modified Le Clanché cells, was the bell battery. Connected to it were five small bells for the use of the Commander-in-Chief and the Commanding Officer to call their stewards and orderlies, and for the Executive Officer to call the master-at-arms. To this same battery were connected five thermostats located one in each of the four coal bunkers and one in the general storeroom. The thermostats were set to give warning when the temperature of the spaces they were in, rose to 140 degrees F. The thermostat consisted of a cylindrical metallic case within which, and insulated from it, was a metallic spiral spring composed of two strips of metal of different expansibilities

under heat, soldered together and coiled into a spiral. The most expansible metal was on the inside of the spiral. As the temperature rose, the spring uncoiled and when the temperature rose to the point for which the instrument was calibrated, the end of the spiral made contact with a lug on the case and the circuit was completed. An annunciator and bell were located near the cabin door, where the captain's orderly could see which space had attained a dangerous temperature.

At the same time that electric firing of torpedoes was being perfected, experiments were being conducted with electrically controlled moveable torpedoes and torpedo boats. Among these was the Lay torpedo. It was a cigar-shaped vessel, approaching the form of our present torpedoes. It was twenty-three feet long and weighed about a ton. The first Lay torpedo purchased by the Government was delivered early in 1873. It was propelled by carbonic acid gas and controlled by electricity, a cable being paid out from the torpedo as it advanced through the water. Much trouble with the gas-making apparatus and the gas chambers in the torpedo developed, and it was not until 1875 that a torpedo was perfected which would function at all. Experiments were made on various models of this torpedo until the early '80's, but it did not prove sufficiently successful to be issued to the service.

The electric control was effected by means of a battery—thirty-six cells in series being used with one type of torpedo—a five conductor cable, a "pole-changer" and switchboard and a series of solenoids in the torpedo. By means of these solenoids, the torpedo could be started or stopped, steered to port or starboard, the indicators for showing the position of the torpedo (by day a vane and by night a light) raised or lowered, the rudder indicator operated, and the charge in the magazine fired.

The solenoids for the first three operations actuated a slide valve, the movement of which allowed gas to get on one side

or the other of a piston. By means of the pole changers, the valves were moved in the direction desired, thus opening or closing the throttle of the propelling engine, raising or lowering the position indicators and moving the rudder to port or starboard. For indicating the position of the rudder, the following device was used in combination with two pole changers on the keyboard:—The pole changers were geared together by insulated toothed wheels, which were fixed on the spindles of the pole changers so that the latter worked accurately together and maintained the same relative position to each other. One pole changer was connected by one of the wires in the cable to a shunt on the torpedo. This shunt was connected in turn to a set of magnets arranged in combination with the valve of the engine that drove the steering apparatus. This valve allowed gas to enter the steering engine and move the rudder to port or starboard. In order that the operator on shore might know the exact position of the rudder at any moment, a series of pins fixed on an arc on the rudder post and arranged in combination with an insulated spring projecting into the path of these pins, was employed. This spring was connected by one of the cable wires to the second of the two pole changers so that the current for indicating the rudder position would be reversed at the same time the current for moving the rudder was reversed. A separate battery was connected with the indicator on the keyboard so that a constant current was maintained between this index and the indicating apparatus on the torpedo.

The current passing from the spring to the shore was made to indicate the position of the rudder as follows: The indicator mechanism consisted of two magnets with a vibrating armature pivoted to oscillate between them. This armature was connected through gears and ratchets to the indicator pointer. Thus the indicator pointer was connected to the spring near the arc on the rudder post of the torpedo. As

the rudder moved in either direction, the pins on the rudder arc came in contact with the spring and a succession of impulses was sent through the wire to the armature. At each movement of the armature, the indicator pointer was moved one step to the right or left, thus indicating at all times the position of the rudder.

The firing of the torpedo was accomplished by a combination of electrical and mechanical means. Two resistance coils were used, one on shore and one in the torpedo. These coils were in series and had sufficient resistance so that when both were in circuit, the torpedo could not be fired, but with either cut out, the battery would explode the primer. If the torpedo was to be fired from shore, the shore resistance coil was cut out and upon closing the switch, the circuit was completed through the other coil and the primer, and the charge was exploded. If it was desired to fire on contact, the firing switch on shore was closed. With the two coils in series, the torpedo would not fire. On contact with the target, a plunger on the nose of the torpedo was driven in, short circuiting the coil in the boat, and the charge was then exploded.

In another type of torpedo, arrangements were made for opening with a solenoid a valve which allowed sufficient water to enter the torpedo to sink it. Another solenoid operated a valve which allowed gas from the gas chamber to expel the water and so to raise the torpedo again.

To prevent the expanding carbonic acid gas from freezing, another model of the torpedo had an alcohol lamp which could be lighted off by an electric spark actuated from shore. The gas was thus superheated sufficiently to prevent its freezing.

The Lay torpedo was experimented with for several years and in smooth water it could be made to function with some degree of success. Its range was but a mile and a half however, and its speed did not come up to the expected nine knots

at that range. The greatest speed obtained on the trials at Washington was about six and three-quarters knots. It was very delicate and unreliable and complications of a trailing cable, numerous magnets, poorly insulated cable and the necessity of carbonic acid making machinery, all militated against its use on sea-going vessels.

The performance of the Whitehead torpedo about this time showed its superiority to other types, and the Lay torpedo was abandoned.

During the year 1876, an investigation was begun at the Torpedo Station to determine the relative merits of several of the most noted dynamo-electric machines then before the public and their applicability to the purpose of producing electric light. Among the machines experimented with, were the Gramme, the Wilde, the Farmer, and the Siemens.

The Gramme machine was a small one using about one horsepower to drive it at 1,800 revolutions per minute, and producing a light varying from 275 to 425 candle-power while running at that speed. It was a series generator with an armature resistance of .6 ohm and a field resistance of about 1.3 ohms.

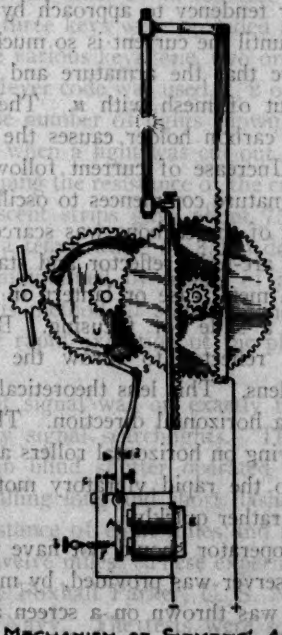
The Wilde machine was an alternating current generator with two armature circuits. One circuit was connected to a commutator and supplied current for the field, while the other circuit provided current for the external circuit. The machine ran about 600 revolutions per minute, and the lamp gave out about 3,600 candle-power. Something over 6 horsepower was necessary to maintain this power.

The Siemens' machine was found to be very satisfactory. It was of a type used in the British Navy (1874) for the production of electric light previous to its test at the Torpedo Station. It was the largest and most powerful machine in use at the Station at this time. The Siemens' generator was a series machine with four field coils. The armature contained

about 100 pounds of wire and the field some 360 pounds more. At the normal speed of 370 revolutions per minute, forty to fifty ampères were devoloped at a voltage of about 50. About 4,000 candle-power was obtained at the normal running speed. The machine was strong and well built and did not give much trouble. The commutator brushes had to be adjusted occasionally in order to keep down sparking. Fig. 8 shows the Siemens' dynamo.

With the Siemens' machine came a very ingenious automatic lamp, having with it a catadioptric apparatus consisting of a small reflector behind the light and a Fresnel lens in front of the arc. The lens was nearly twenty inches in diameter and of excellent construction.

The sketch (Fig. 9) shows the working diagram of the



MECHANISM OF SIEMENS' ARC LAMP.

FIG. 9.

automatic apparatus. E is a magnet with its armature A placed a short distance in front of the poles. A regulating screw *b* with a spiral spring *f* is attached to the lower end of the lever A, forcing it against the stop *d* and withdrawing the armature from the poles of the electro magnet. When a sufficiently strong current traverses the coils of the latter, the armature is attracted, contact is made at *c* and the armature coil is short circuited. The armature is then released, breaking the contact at *c*, the coil is again energized and A attracted. Thus a vibratory motion is produced which continues as long as there is sufficient current to overcome the tension of the spring.

The spring pawl *s* at the end of A actuates a ratchet-wheel *u*, which is in gear with a train of wheels to the carbon holders. It opposes their tendency to approach by pushing them apart tooth by tooth until the current is so much weakened by the length of the arc that the armature and lever cease to oscillate, and *s* is out of mesh with *u*. The preponderant weight of the upper carbon holder causes the carbon points to approach again. Increase of current follows decrease of resistance and the armature commences to oscillate again. In action, the movement of the carbons was scarcely perceptible.

Fig. 10 shows the arc-light reflector and stand. The lens was surrounded by a metal case or lantern in which the arc light was placed on a slide for focusing. Behind the arc was a hemispherical reflector to throw the rays forward through the Fresnel lens. This lens theoretically sends forth all the light rays in a horizontal direction. The entire lamp was capable of revolving on horizontal rollers and was swung upon pivots. Due to the rapid vibratory motion, the lamp mechanism wore out rather quickly.

In order that the operator should not have to look at the arc itself, a focus observer was provided, by means of which an image of the arc was thrown on a screen at the back so that the lamp could be adjusted.

Several machines devised by Professor Farmer, electrician of the Station, were experimented with. The first was a combination of eight type A torpedo-firing generators (Fig. 4). They were geared together to run at a speed of 1,500 revolutions per minute, and would give as much as 5,000 candle-power for a short period at this speed. The internal heating was too great, however, for long continued service.

Other machines designed by Mr. Farmer and manufactured by Wallace and Sons were tested at the Station.

The Signal Officer of the Navy became interested in these machines and lights as he was very desirous of obtaining an efficient night-signalling lamp. Two methods of signalling were tried. In the first, three strips of platinum about 2 inches long, 3/8 inch wide and .003 inch thick, were arranged vertically one over the other about ten feet apart. Three resistance coils and three keys were provided and so arranged that by pressing the various keys, one, two or three lights could be shown. The Meyer code was used, 1, 2 or 3 in this code being indicated by the number of lights shown. The keys were arranged so that when a light was cut out, a resistance coil was cut in, thus keeping the resistance of the circuit nearly constant. These incandescent strips gave about 75 candle-power when maintained at a temperature of 3,000 degrees F. This temperature was maintained by means of an automatic current regulator. This method of signalling never progressed very far, due to the rapid oxidation of the platinum and its great cost.

The arc-light signal was on exactly the same principle as our present-day signal searchlights. The lamp was hooded and a Venetian blind shutter operated by a lever gave the means of signalling long and short flashes. Signals were recorded at a distance of eight miles and the light was seen at a distance of twelve miles. These experiments were witnessed by Commodore Foxhall Parker, U. S. N., then Chief Signal Officer of the Navy. The tests were so satisfactory to him

that the firm of Wallace and Sons, of Ansonia, Conn., was asked to furnish a generator and arc light to the Torpedo Station for test, with a view of purchase and installation aboard ship if satisfactory.

In the fall of 1876, a machine and light were furnished by Wallace and Sons to the Torpedo Station. The whole apparatus was of peculiar appearance and construction viewed from the modern standpoint (see frontispiece).

The generator consisted of four magnets held between two cast iron upright pieces, and a shaft, with bearings in the uprights, carrying the armature wheel. The whole stood on a bed plate, to which the upright pieces were secured. A bolt connected the two uprights for rigidity.

The machine and bed were 23 inches high, 34½ inches long, and 13 inches wide. Four legs were supplied with the machine which when bolted to the bed plate, raised the machine eighteen inches. The entire machine weighed 918 pounds, of which the legs formed 118 pounds, other cast iron parts 576 pounds, copper in fields 138 pounds, copper in armature 45 pounds, brass spools about 20 pounds, and steel shaft about 21 pounds.

The cores of the electro-magnets were cast in one with the uprights, two on each. The field coils were wound on brass spools shaped to fit the cores. They were wound with wire .128 inch in diameter in eight layers of forty-eight turns each—a total of 384 turns. The wire was insulated with braided cotton impregnated with shellac. The resistance of each coil was .601 ohms at 70 degrees F.

The armature wheel was 13 inches in diameter, and on each face carried an armature of twenty-five bobbins. Each of these bobbins had four coils wound on it. A coil consisted of two layers, each of forty-five turns, so that each bobbin carried 360 turns of wire. This wire was .047 inch in diameter and was of copper covered with cotton braid impregnated with shellac.

All the coils on each side of the armature wheel were connected to a commutator having 100 divisions. The resistance of each armature was 4.89 ohms at 70 degrees F.

The commutator brushes, two for each commutator, were of small copper wires bound together and soldered.

The diameter of the armature wheel was such that when revolved, the bobbins were presented in succession opposite the field coils. The air gap between armature and field was about ⅛ inch.

The machine was connected with the field coils in series and the armatures in parallel. The internal resistance of the machine then was 4.85 ohms. $(4 \times .601) + (.5 \times 4.89)$.

When used to produce light, 5.3 horsepower at 770 revolutions per minute gave 13 ampères at 100 volts at the terminals. The arc was about 3/16 inch. Total resistance of the circuit was about 7.5 ohms. Out of the 1,300 watts available at the terminals, some 400 was lost in the field, so that only about 900 watts was available for the arc light. The average candle-power of the arc was about 700. The efficiency of the machine was a little over 30 per cent.

Various experiments were run with the field coils connected in parallel instead of in series, but the results varied so much that little data of value was obtained.

The automatic lamp furnished by Wallace and Sons was very simple in its construction and action. The carbon points were made to approach each other by the greater weight of the upper carbon-holder and, when the two carbons were in contact, were made to separate and afterward maintain the requisite distance by the attraction of two axial magnets on their cores or armatures.

The upper carbon-holder had a long bearing and was suspended by two thin metal bands, secured to the circumference of two metal wheels of equal diameter situated on opposite sides of the carbon-holder. On the axles of these wheels were two similar wheels of half the diameter. From these latter

wheels the two axial magnet cores were suspended. A cross-head, to which was fixed the lower carbon-holder, connected the two armatures. By this arrangement, the upper carbon travels at twice the rate of the lower carbon and when the upper is connected to the positive side of the line, the light maintains a constant position.

The magnet coils were in the light circuit and the action of the lamp was as follows: With carbons in contact, when the current is turned on, the armatures are attracted downward, carrying with them the lower carbon-holder, and by means of the metal suspending bands, producing a partial revolution of the large and small wheels. This movement caused the upper carbon to move upward twice the distance that the lower carbon had moved downward. As soon as the carbons were separated, the arc was struck. With the resistance of the circuit decreased, the pull on the solenoids was lessened and the weight of the upper carbon-holder tended to bring the carbons into contact, thus decreasing the resistance and increasing the pull on the solenoids, which would again separate the carbons. When the upper carbon-holder was properly weighted, the arc was very steady. The carbons would burn only an hour, which was found to be a disadvantage.

This apparatus was installed on the U. S. S. *Hartford* and was tried out for many nights while the vessel was off the South American coast in 1878. The ship did not find the outfit very satisfactory as the grooved armature wheel broke from the centrifugal stresses set up. The perfection about this time of the Very rocket system of night signals caused the signal searchlight to be abandoned for many years. It is believed that the *Hartford's* light was looked on as little more than a toy during its test, for a number of officers who were on the vessel at this time (1878) fail to remember its existence.

Experiments were made at the Torpedo Station in 1877 with the telephone, in order, as the report says, to ascertain

its suitability for communication between the bridge and powder magazine, as well as other parts of a ship. It was found feasible to communicate over a circuit having a resistance of 22,000 ohms and a capacity of 8 microfarads. The report also stated that it would be entirely feasible to communicate through an ocean cable at least five hundred miles long. This optimistic prediction has never been fulfilled as far as the author knows, although trans-Atlantic telephony is said to be possible by the use of a cable composed of spaced repeating coils invented by Professor Pupin. This system will probably never be attempted because of the success of radio telephony.

In 1879, the steam launch *Success* was fitted up at the Torpedo Station as an electrically-controlled torpedo boat. This boat was an English-built, so-called lifeboat launch, and was fitted with Herreshoff boiler and engines. By means of magnets, controlling valves and fittings, and energized from a shore battery through a five conductor cable paid out as the boat advanced, it could be started, stopped or backed, turned to starboard and port, two countermines could be dropped and fired and a spar torpedo carried on the bow could be dropped and fired. The controlling devices for this boat were of much the same nature as those used in the Lay torpedo and were open to the same objections.

In 1881-82, Captain Thomas O. Selfridge, U. S. N., then in charge of the Torpedo Station, devised a system of electric lighting for war purposes.

In his report he said, "A light for this purpose should be one that, as far as possible does not light up the ship from which it is thrown; should slowly but constantly revolve back and forth lighting successively arcs of the horizon and at the same time can be easily and quickly thrown and kept upon any object at rest or in motion."

To fulfill the above conditions, the following apparatus was assembled:

A Brush generator designed to supply current for three arc lamps in series.

Two Brush arc lamps arranged with motors and shunts as described below for searchlights.

As the machine purchased could carry three arc lamps and only two were purchased, the capacity for the third was taken up by twelve Maxim incandescent lamps arranged in parallel —five in the wardroom, two in the engine room, two on the berth deck, and three for the running lights. These Maxim lamps were similar to Edison lamps in appearance, the filament being of paper instead of bamboo fibre.

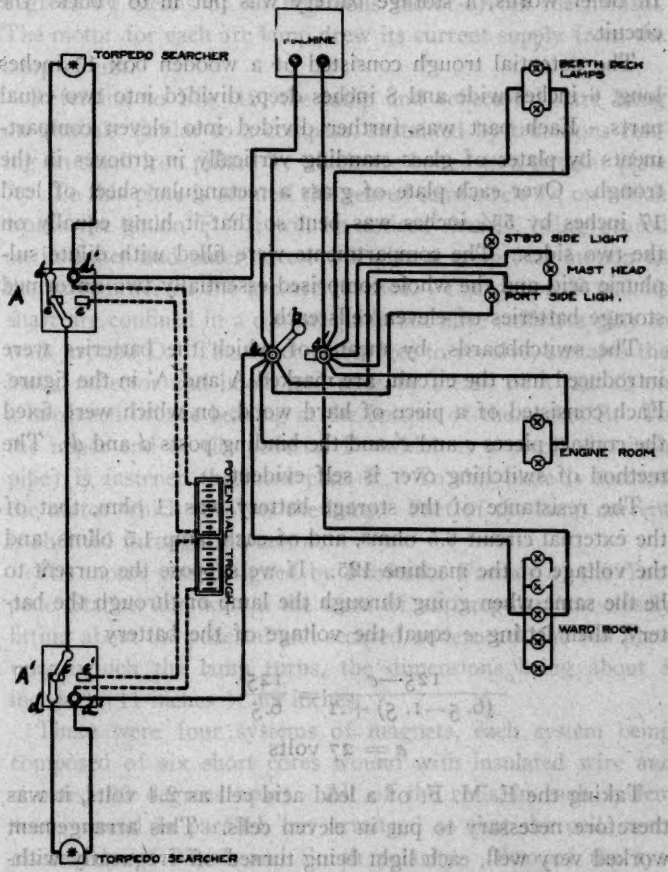
A "potenial trough," described below, was used to regulate the system when one or both arc lights were cut out.

The dynamo was located on the berth deck, where it was driven by a pumping engine. Four insulated wires led from this deck through the forward coal bunker and up to the drum-room above the boilers. Two of these wires conveyed the main current from the machine, the other two carried a branch circuit to the berth-deck lamps.

In the drum-room were placed two terminal binding posts *a* and *a'* (see Fig. 11), having a switch *b* between them. One of the generator leads came to this switch, the other leading to a switchboard A in the pilot house.

The circuits for the incandescent lamps came off at the switch *b*. As the resistance of each incandescent lamp when hot was 16 ohms, the twelve lamps in parallel had a resistance of 1.33 ohms, very nearly the same as an arc light.

As it was desirable to have a means of extinguishing one searchlight without diminishing the illuminating power of the other or so increasing the current as to endanger the circuit, it was necessary to adopt some method of keeping the current unchanged when a lamp was thrown out of circuit. No reliable rheostat being on hand, Lieut.-Comdr. Caldwell devised a potential trough by means of which a difference of potential equal to that between the terminals of an arc lamp was opposed



ELECTRIC LIGHTING SYSTEM ON BOARD U.S.S. NINA. 1881

FIG. 11.

to the E. M. F. of the machine when the lamp was thrown out. In other words, a storage battery was put in to "buck" the circuit.

The potential trough consisted of a wooden box 15 inches long, 6 inches wide and 8 inches deep, divided into two equal parts. Each part was further divided into eleven compartments by plates of glass standing vertically in grooves in the trough. Over each plate of glass a rectangular sheet of lead 17 inches by 5¾ inches was bent so that it hung equally on the two sides. The compartments were filled with dilute sulphuric acid and the whole comprised essentially two unformed storage batteries of eleven cells each.

The switchboards, by means of which the batteries were introduced into the circuit, are marked A and A′ in the figure. Each consisted of a piece of hard wood, on which were fixed the contact pieces c and c' and the binding posts d and d'. The method of switching over is self evident.

The resistance of the storage battery was .1 ohm, that of the external circuit 6.5 ohms, and of each lamp 1.5 ohms, and the voltage of the machine 125. If we suppose the current to be the same when going through the lamp or through the battery, then letting e equal the voltage of the battery

$$\frac{125-e}{(6.5-1.5)+.1} = \frac{125}{6.5}$$

$$e = 27 \text{ volts}$$

Taking the E. M. F. of a lead acid cell as 2.4 volts, it was therefore necessary to put in eleven cells. This arrangement worked very well, each light being turned off frequently without affecting the other. It is evident, however, that continued running with one light cut out would overcharge the battery and that finally the plates would disintegrate unless the battery were discharged at intervals.

The lamps were of 4,000 candle-power and were fitted with locomotive reflectors. One lamp was located amidships on

each beam of the *Nina*, fitted with a hood and revolved 180 degrees by means of an ingenious motor-driven mechanism. The motor for each arc lamp drew its current supply from the lamp circuit.

Referring to Fig. 12, the lamp and reflector U are hung on gimbals similar to a compass, sustained by trunnions resting on small iron pillars T, which are bolted to a circular plate A. To this plate is secured the geared semi-circle D, on which works the pinion F. It will be noticed that D, being geared on its inner and outer faces, will give a reciprocal motion as the extremities of the arc are reached. The pinion F and its shaft are confined in a conical guide but have sufficient play to walk around D. The upper plate, free to revolve, sustains the lamp, reflector and hood, and rests by means of a bolt O on a hardened bronze bearing at the bottom of the socket B. To the upper end of the pedestal P (which is a piece of 5-inch pipe) is fastened the fixed plate R. To this plate is secured the motor which revolves the lamp. Part of the lamp current is shunted through the motor.

The motor was designed by Professor Farmer of the Torpedo Station and was in the form of an irregular box closely fitting about the pedestal and secured underneath the bed plate upon which the lamp turns, the dimensions being about 8 inches × 11 inches × 62 inches.

There were four systems of magnets, each system being composed of six short cores wound with insulated wire and situated 60 degrees apart. All of the coils in each system were wound in parallel, but arranged so that the coils were alternately of North and South polarity. Two of the systems comprised the field and were fixed one at each end of the box, the magnetic circuit being completed through the iron ends of the box. The other two systems of bobbins were fixed to soft iron discs mounted on a shaft, the whole comprising the armature. The armature bobbins were so placed that when all were opposite to the field bobbins at either end,

those at the other end were midway between their fixed bobbins. Each set of movable bobbins had a commutator and brushes. The motor was series wound, the current going through the two sets of field bobbins in series and then through the two sets of armature bobbins in series.

The resistance of the motor was less than half an ohm. The shunt had about the same resistance in order to obtain a half revolution of the lamp per minute. The motor revolved about 600 revolutions per minute and this motion was geared down through a worm and pinion to a gear wheel which turned the pinion F. When during the revolution it was desired to stop the lamp and point it in a certain direction, the arm M was turned, which disconnected the pinion H from the worm L, at the same time breaking the motor circuit. The arm N working directly on the gear train turned the lamp to any desired bearing.

The installation of incandescent lamps was the first made on a vessel in our service and although incidental to the searchlight installation, paved the way to the electric lighting plant on the *Trenton* in 1883. (The *Trenton's* installation was described in the August, 1920, JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS.)

The foregoing comprises, it is believed, the most important as well as the most interesting points of electricity in the Navy during the period covered. It must be remembered that from the close of the Civil War up until the early '80's, the Navy was in a rather parlous condition. Little money was appropriated for building and very little for experimenting.

The successful exploitation of the incandescent lamp and especially the building of large reliable generators to run these lamps gave an impetus to electrical development in the Navy as in civil life—an impetus which still carries on the forward movement to ends unthought of by these pioneer experimenters in the electrical field.

NOTE.

The following references were consulted in writing this article:

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U. S. Naval Institute.
Franklin Institute.
Smithsonian Institute.

EX-GERMAN BATTLESHIP *OSTFRIESLAND.*

By Lieut.-Comdr. Karl F. Smith, U. S. Navy,
Member.

The Ex-German Battleship *Ostfriesland* was a ship of the first line, started in 1909 and launched in 1911. Length over all is 548 feet, 2 inches, with an extreme breadth of 94 feet. Normal draft is approximately 28 feet 6 inches, giving a displacement of 24,064 tons. It has been reported that the *Ostfriesland* showed remarkable sea going qualities, behaving extremely well in a sea way. This, however, has not proven the case on present runs, due, probably, to absence of the stores normally carried in the lower positions. While at the Dock Yard, Rosyth, an inclining experiment was made to determine the metacentric height and location of center of gravity and center of buoyancy. Dimensions were taken from a small scale drawing found on board and sketches of the amidship sections and water planes checked up by dimensions taken aboard ship. At the time of the experiment, the displacement was 20,552 tons; a weight of 60 tons was placed at a distance of 37 feet from the middle line to incline the ship. A pendulum 25 feet long was used to measure the list. The normal swing was found to be 1 1/16 inches for each 15 tons dead weight, added. From the formula—

$$G.M = \frac{w \times d}{W \tan\theta} = \frac{15 \times 37}{20{,}582 \times \frac{1\frac{1}{16}}{25 \times \frac{1}{2}}} = 7.6$$

we see that the G.M. is 7.6 feet. From the metacentric diagrams at 24 feet 6 inches mean draft, it was found that B was 10.6 feet below the water line. At 28 feet 6 inches draft,

B was found to be 12.4 feet below the water line. M was 40.2 feet above the keel, therefore G is equal to 40.2 minus 7.6 or 32.6 feet above the keel. It is unusual to find so large a metacentric height on a vessel of this type. The *Ostfriesland* was one of the Flagships at Jutland and from reports received

Flooded Compartments	Water (Tons)	List Deg.-Mins.	Change in draft (Centimetres), Forward: Increase	Forward: Decrease	Amidships: Increase
Carpenter's Stores	65	21 Star.	6	1	3
Clothing Room	61	24 Star.	8	2	3
Magazine K8	84	28 Star.	8	2	3
Starboard Dynamo Room	137	44 Star.	16	6	5
Passageways	89	54 Star.	8	2	3
Protection Bunkers	55	28 Star.	5	1	2 6
Total due to leak	511	3-17 Star.	50	14	19
Compensating flooding (Probably bottoms and tanks)	383	2-14 Port	5.7	17.4	18
Total	894	57 Star.	55.7	31.4	37
Flooding Magazine K12	66	22 Port	8.0	2.0	3
Final data	960	35 Star.	63.7 or 25.2 inches	33.4 or 12.2 inches	40 or 15.8 inches

TABLE 1.

Knots	Revolutions per Minute: 3 Engines	2 Engines	1 Engine	Boilers
5	30	33	35	6
6	35	41	48	6
7	40	50	60	6
8	45	55	66	6
9	50	62	74	6
10	55	69	80	7
11	60	75	85	7
12	65	81	90	8
13	72	88	97	9
14	78	95	103	10
15	84	102	110	12
16	90			14
17	97			14
18	103			15
19	110			15
20	118			16
21	128			15
H.P.h. per knot at 10 knots	5.5	6.9	8.0	
Slip %	19.0	35.0	44.0	
H.P.h. per knot at 15 knots	5.6	6.75	7.35	
Slip %	21.0	34.8	39.1	
H.P.h. per knot at 21 knots	6.1			
Slip %	26.8			

TABLE 2.

from British sources, inflicted considerable damage on the British Fleet, especially on H.M.S. *Warspite*. From all information at hand, and appearances of compartments, it is believed that the *Ostfriesland* was mined or torpedoed at Jutland or on returning to port after action; the torpedo or mine

piercing the skin of the ship on the starboard side forward between frames 80 to 90 causing the flooding of the following compartments:

(*a*) Carpenter's store room.
(*b*) Starboard clothes room.
(*c*) Magazine K8.
(*d*) Starboard dynamo room.
(*e*) Outer lower passageways, frames 80 to 94.
(*f*) Outer upper passageways, frames 80 to 94.
(*g*) Protection bunkers.

The data, given in Table 1, apparently worked out at the time of the accident, is interesting, as it shows the actual trim and list after the accident, and when finally corrected.

CONDITION ON TAKING OVER THE "OSTFRIESLAND."

The *Ostfriesland* with a German crew aboard, was towed to the Firth of Forth by another German Battleship, *Nassau.* Steam was on two boilers for auxiliary purposes and for steam steering.

Immediately upon the arrival of the *Ostfriesland* off Burntisland an inspection party of officers and men from the *Chattanooga, Panther* and destroyers moved aboard to inspect the ship.

The Germans tried to light off fires in dead boilers, but this was stopped in time. On the arrival of the *Hancock* with the *Ostfriesland* detail a thorough inspection was made and showed the machinery to be apparently in fair condition, but with all piping of brass or copper removed, all gauges gone, and leads chopped and disconnected wherever possible. The Germans evidently attempted to damage all motors before leaving ship and had disconnected all motor generators apparently with the intention of removing them. They had torn apart or cut in two all electrical leads to cranes and winches and auxiliary machinery.

All pipe lines showed considerable corrosion, bolts and nuts being frozen and badly corroded and valves frozen shut on steam and drainage lines. An attempt had been made to remove all drawings which would be useful to the Americans, and what few drawings were found, had been deliberately mutilated in an attempt to make them illegible. This was especially true of the plans of the drainage and steam lines. The conditions were such that it was considered absolutely necessary to test all the lines and examine all valves, but it became evident that practically the entire steam piping of the ship would have to be packed as the packing had deteriorated to such an extent that no expansion joints could be set up. It took nearly two weeks to free the valves and bolts throughout the engineering department so that the pipe lines might be removed for test. While the first official inspection seemed to indicate that ninety days at least would be required to put the ship in condition, after considerable cleaning was done, the condition of the machinery was found better than was expected and repairs were completed forty-eight days ahead of the estimated date of completion.

Considerable vandalism was found throughout the department, and the Germans had deliberately befouled all spaces where a man could possibly go. Human feces were found in bilges, in corners, in wash basins and even in officers' staterooms and baths. Owing to the absence of any drawings, during the first two weeks considerable difficulty was experienced in clearing the ship of water. Attempts to pump out one bottom or compartment would lead to flooding another compartment in the extreme end of the ship. As soon as the lines were traced out, this difficulty stopped in a big measure. On leaving Rosyth, after docking, all machinery of the ship, both electrical and steam, was in commission, except the four forward generators and turret gear. The four forward generators were dismantled to supply spare parts for the after four. This

was done for the reason that the forward starboard generator rooms had been under water and the insulation of the generators badly affected.

The following is a general description of the Engineering department of the *Ostfriesland.*

MAIN ENGINES. (SEE FIG. 1.)

The main engines are in separate water tight compartments with no communication between them except by water tight voice pipes and telephones. Water tight bulkheads are carried to the second deck, well above the water line. Lubrication is wholly wick or gravity feed (see special features). Water service is provided to all bearings and crosshead guides. All valve stems and piston rods are soft packed, the rods having adjustable stuffing boxes (see special features). All cylinders, except high pressure, are provided with operating valves similar to the old Lancaster, but no by-passes are fitted; this has a tendency to cause engines to stick on center when maneuvering. There are three four cylinder, triple expansion engines with cylinders 42 × 63 × 67 × 67 inches, stroke 48 inches, estimated indicated horsepower 26,000. All cylinders have piston valves; one on high pressure and two each on intermediate and low pressure. The crank sequences are H.P., F.L.P., I.P., A.L.P. The H.P. and F.L.P. cranks are at right angles; the I.P. and A.L.P. being placed as nearly as could be determined 190 degrees from the H.P. and F.L.P., respectively. This, in conjunction with the varying crosshead widths, is apparently an attempt at more perfect crank balance. The Wing Engines are out turning and the Center Engine right handed.

Diam. Piston rods–H.P. 7 3/4 inches, I.P. 8 inches, F.L.P. 8 inches, A.L.P. 6 3/4 inches.

Diam. Valve stems–H.P. 4 1/8 inches, I.P. 3 inches, F.L.P. 3 inches, A.L.P. 3 inches.

Diam. Crank shaft–17 inches.

Diam. Crank pin–17 inches.

Diameter cross head pins 9 3/4 inches; varying lengths. The cylinders are not jacketed. There are brakes on all shafts to keep propellers from turning over when engine is idle and to allow coupling up underway.

From data found aboard, the German method of operating is indicated. (See Table 2.)

MAIN CONDENSING PLANT.

The main condensers, together with their air and circulating pumps are in separate water tight pump rooms, which are abaft their respective engine room compartments and are entered through water tight door from stairway leading to engine room. All stairways are in water tight chutes from engine room doors to berth deck. All condensers are cross connected so that any or all condensing units may be used on any engine combination, an additional valve (butterfly) being installed between each engine and the main exhaust cross connection. (See Fig. 2.) The auxiliary exhaust can be turned into main exhaust through a valve in the middle engine room. Condensers are of usual type.

Length	11 feet 6 inches.
Diameter	8 feet 2 inches.
Tube diameter	11/16 inch.
Tube length	9 feet 10 3/4 inches.
Tubes, number	5100.

Cooling surface 9,000 square feet, approximately. This would give a ratio of $\frac{\text{cooling surface}}{\text{indicated horsepower}} = 1.04$ at full power (approx.).

CIRCULATING PUMPS.

The main circulating pumps are centrifugal with suction connections to main injections and main drain lines or through main to auxiliary drain lines. Discharges are to main condensers or when on main or secondary drains, by-passed over-

board through by-pass in division plate of condenser. The engine is compound, 8 × 12 × 8 inches.

AIR PUMPS.

Single acting.
Steam cylinder.
Water cylinder. 40 inches, diameter.
Stroke, 24 inches.

THRUSTS, SPRING BEARINGS, ETC.

Thrusts are of ordinary horseshoe type with eight collars and seven shoes. Spring bearings are of usual type. Stern tube stuffing box is of usual type.

SHAFT.

Thrust shaft..... 16 inches diameter.
Line shaft..... 16 inches diameter.
Tail shaft..... 16 inches diameter.

PROPELLERS.

Four bladed, adjustable, detachable blades. Increasing pitch, hub to tip. Diameter, 18 feet. Average pitch, 22 feet 9 inches. Data taken while in dock by clinometer, on starboard blade after face.

Diam. feet.	Entering.		Leaving.				Average.
	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Ft. In.	Feet.	Ft. In.
6	23 ..	21 3	21 9	20 6	18 6	...	21 ..
8	23 ..	21 3	21 9	20 6	20 ..	20	21 1
10	22 9	22	21 9	22 9	21 6	21	21 11
12	22 6	22 9	22 6	22 3	21 6	23	25 5
14	24 ..	23 9	24 2	23 6	... ..	...	23 10
16	24 ..	25 9	29 3	... ..	... ..	...	26 4

It will be noted that the pitch is greater on the entering edge. Only one blade was pitched and I am under the impression that the blades have been accidently inter-changed. Time was not available to check other blades.

REVERSING AND JACKING ENGINES.

The reversing engine is of the usual type, steam operated, through worm and gear.

The jacking engine is electrical with hand connections.

SHAFT BILGE PUMP.

On the forward end of each main engine is a single acting shaft bilge pump, 7 inches × 7 inches.

EVAPORATORS AND DISTILLERS.

There are four evaporators, small bent tube type, similar to the Weir type, of about 145 square feet of evaporating surface each. No reducing valves are provided, but coil pressure is regulated by wire drawing. These evaporators are located two in each wing engine room. One distiller of ordinary type and carbon filter box is situated in each wing engine room.

There are two distiller circulating pumps, of the duplex type, 4 × 5 × 4 1/2 inches, in each wing engine room. Evaporator feed is taken from distiller discharge.

This installation was apparently built with the intention of using only on make up feed at sea, as the distiller capacity is limited to one evaporator. Running on make up feed, the vapor discharges through spring loaded valve directly to auxiliary exhaust line and then to main or auxiliary condenser, thence through air pump to main feed tanks whose overflow runs direct to double bottoms.

MAIN FEED TANKS.

One feed tank with ordinary baffles, and filter boxes in each engine room. The overflow runs to reserve feed tanks. Tanks are equalized through main feed line.

BOILER STATION. FIGS. 1 TO 5.

The boiler spaces run from frames 54 to 75 (note German numbering is from aft), leaving a magazine space of nine frame spaces between after fire room and forward engine room.

There are three groups of fire rooms, the forward group, containing three boilers and apparently used for auxiliary purposes. The after two groups contain six boilers each, three abreast with working platform between. These groups are divided by fore and aft water tight bulkheads into nine separate fire rooms, three containing but one boiler and six containing two boilers each. These bulkheads are carried to the protective deck.

There is no communication between groups except by voice pipe and telephone.

BOILER STATION.

The main boilers are of the Schulz-Thornycroft Type, similar to our Ohio type with 1,428 tubes per boiler. The tubes are 1 3/8 inches (O.D.) and divided into three nests, forming two furnaces. Tube lengths (mean) of wing nests 11 feet 7 1/4 inches (approximate) and of center nest 8 feet 8 1/2 inches (approximate). The main steam drum constructed in two sections, upper half 3/4 inch and lower or tube sheet 1 3/8 inches, is 55 inches in diameter and 106 inches long.

The mud drums, three in number of 5/8 inch plate are 21 1/2 inches inside diameter and 106 inches long and are cross connected at the rear by a 10 inch circulating pipe 16 feet 8 inches long.

The furnaces, two per boiler, have a grate surface of 49 square feet, or a total of 98 square feet, for each boiler. Each furnace has three fire doors or six doors per boiler.

Boilers are fitted for burning oil in conjunction with coal, one burner being installed over the middle door of each furnace.

BOILER FITTINGS.

Main and Auxiliary Feed Stop and Check Valves.

Stops and Checks are of the ordinary type but differ from our practice in that there is but one boiler stop connected by a Tee to main and auxiliary checks.

INTERNAL FEEDS.

The internal feed leads into center of the main drum and extends back about three quarters the length of the drum and is perforated both top and bottom.

BOTTOM AND SURFACE BLOWS.

Scum pan is circular, about two feet in diameter, located near the front end of the drum and connected through the surface blow line to the master valve.

Bottom blows are connected to each mud drum, the wing drums being connected by a flange and goose neck to bottom blow lines, the center drum having similar connection on front head.

All blows, both surface and bottom, are controlled through their own valves, and in addition there is a globe master valve controlling all. From the master valve blow lines are connected to a four way valve having connection to bilges, overboard discharge, and reserve tanks.

AIR COCKS.

Air cocks are of the ordinary type.

AUTOMATIC FEED.

Each boiler is fitted with automatic feeds which have now been disconnected.

GAGE GLASSES.

Gage glass fittings, two to each boiler, are a decided improvement over the usual type. The glasses are installed in a

fitting having a ball face socket fitting over a ball joint attached to steam drums. The upper fitting is attached to a valve stem which can be moved to clamp or release the frame. With this arrangement, a gage glass complete can be removed and replaced in less than half a minute.

FIRE EXTINGUISHERS.

Each boiler is equipped with fire extinguishers, four to a boiler. These are located at the front and rear of each furnace. Salt water is taken from the wetting down line through a horizontal globe valve having a very coarse thread on the valve stem. A lever coming through the floor plates connects with this valve. The valve is completely opened by throwing this lever to the "on" position.

SAFETY VALVES.

The safety valves, two to each boiler, are plain flat seated valves, controlled by a flat steel spring about 16 1/2 inches long. Two studs secured to the valve body have a strap passing over the top of the springs and this forms the only adjustment for lifting as there are no timing or adjusting rings. This valve is enclosed in a plain cylindrical casing. There is no adjustment to insure reseating at a determined pressure.

A reach rod from the floor plates permits raising a valve by hand or locking shut for testing without the use of gags. In case of valve failing to seat, this may be used to seat the valve.

BLOWERS.

The blowers for the forward three and after six boilers, one for each boiler, are driven by compound engines, opposed, with inclined cylinders 5 29/32 × 9 27/32 × 4 7/8 inches. These operate at full boiler pressure.

Blowers for the middle group of firerooms are turbo driven with reduction gears. These blowers have an independent circulating pump for water service or can take water from

flushing and fire mains. Forced lubrication is obtained by means of a chain driven oil pump. Closed fireroom system is used throughout.

PUMPS.

In each group of fire rooms there is one Main Feed, one Auxiliary Feed and one Fire and Bilge Pump. The Main Feed pumps are located in the starboard wing fire rooms and are all duplex. The Auxiliary Feed Pumps are located in the port wing fire rooms and are also duplex. The middle and after fire room fire and bilge pumps are duplex, Weir type, and are located in the center fire rooms of each group. The forward fire room fire and bilge pump is simplex.

PUMP SIZES.

Main Feed.

Forward Group, 11 7/8 × 7 1/2 × 13 inches.
Middle Group, 15 × 10 × 16 inches.
After Group, 15 × 10 × 16 inches.

Auxiliary Feed.

Forward Group, 11 13/16 × 7 11/16 × 14 inches.
Middle Group, 15 × 10 1/16 × 16 inches.
After Group, 15 × 10 1/16 × 16 inches.

Fire and Bilge.

Forward Group, 13 3/8 × 8 3/8 × 18 inches.
Middle Group, 11 7/8 × 7 15/16 × 16 inches.
After Group, 11 7/8 × 7 15/16 × 16 inches.

ASH EJECTORS.

In each fire room is an ash ejector hopper (nine hoppers). Ash ejectors are similar to the See Type with above water discharge.

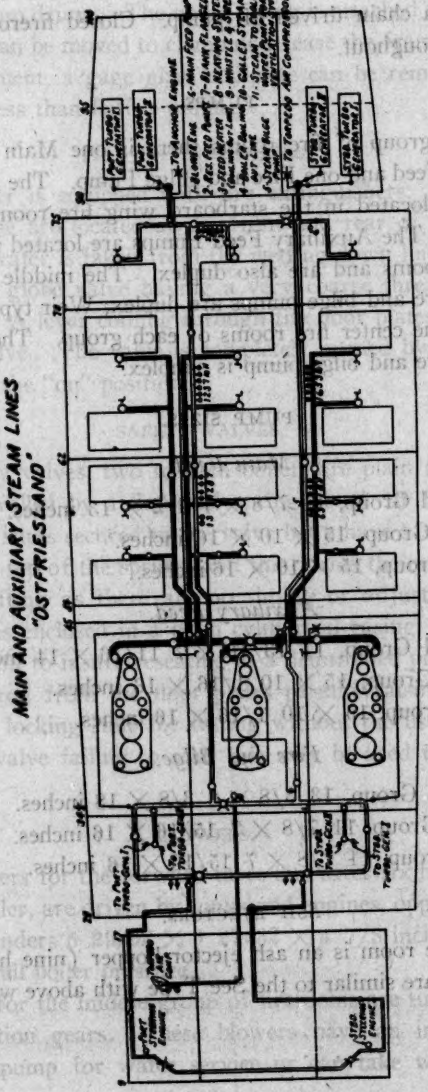

FIGURE 1

MAIN STEAM LINES.

It will be noted from Fig. 1, that the forward three boilers are not connected directly to the main steam line, and were apparently designed to do all of the auxiliary steaming in port. There are three main steam lines in middle and after fire room groups, in the port, middle and starboard fire rooms, respectively. It is apparent, not only from the fact that the piping from the port fire room was brought amidships, but also from the fact that all important wiring is carried on the starboard side of the ship, that the German tactics probably contemplated port side action whenever practicable. The boilers of the middle group of fire rooms have no cut-out between the boiler stops and main steam line. The cut-out for the middle group of fire rooms is located in the after fire-rooms, this necessitates two boilers being killed in the middle group to work on any one boiler or steam line.

The after boilers are all provided with a cut-out between the boiler stop and main steam line. The connections of all main lines into the cross connection of the three engines are in the center engine room.

Underway, to use the forward three boilers which are connected through the cross connection to both sides of the auxiliary steam line, two cross connections to the main steam line are provided in the center engine room.

All cut-out valves of the main steam line, as well as boiler stops can be closed from the protected deck by means of reach rods. These reach rods are provided with ratchets which allow movement of the valve in one direction only. The valves may be closed from deck but must be opened from below. This is a decided advantage over most of our installations.

AUXILIARY STEAM LINE.

The auxiliary steam line, as will be seen from Fig. 1, is a double loop system, so constructed that no matter what section is damaged, steam may be sent to any piece of machinery

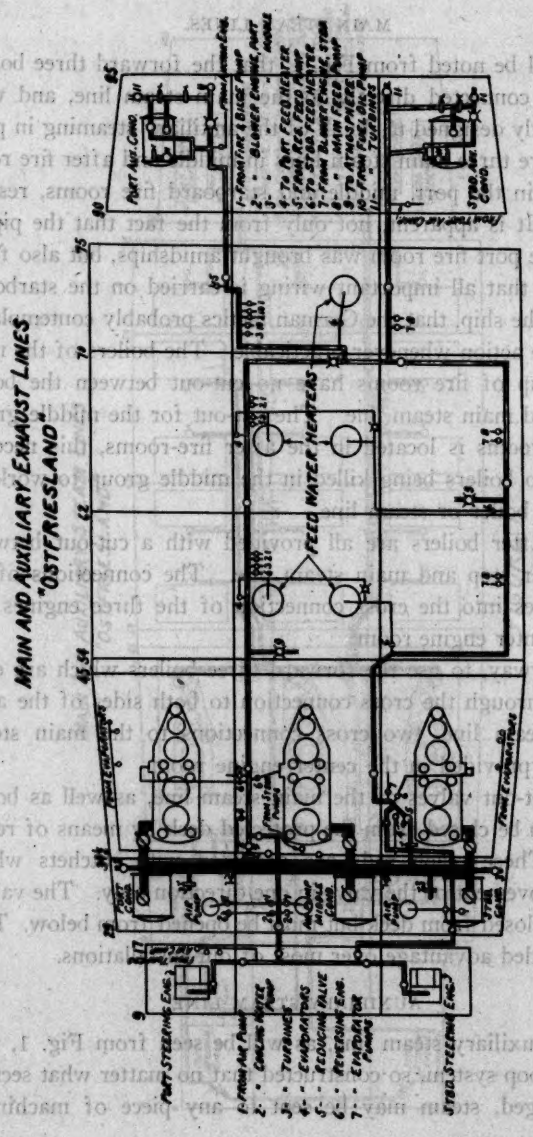
MAIN AND AUXILIARY EXHAUST LINES
"OSTFRIESLAND"
FEED WATER HEATERS
PORT STEERING ENG.
STBD. STEERING ENG.

FIGURE 2.

FEED LINES "OSTFRIESLAND"

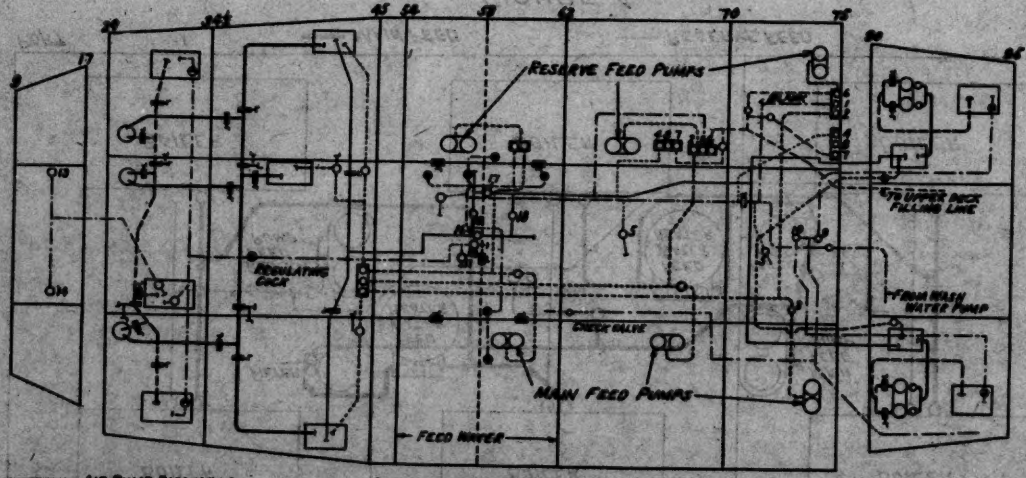

FIGURE 3

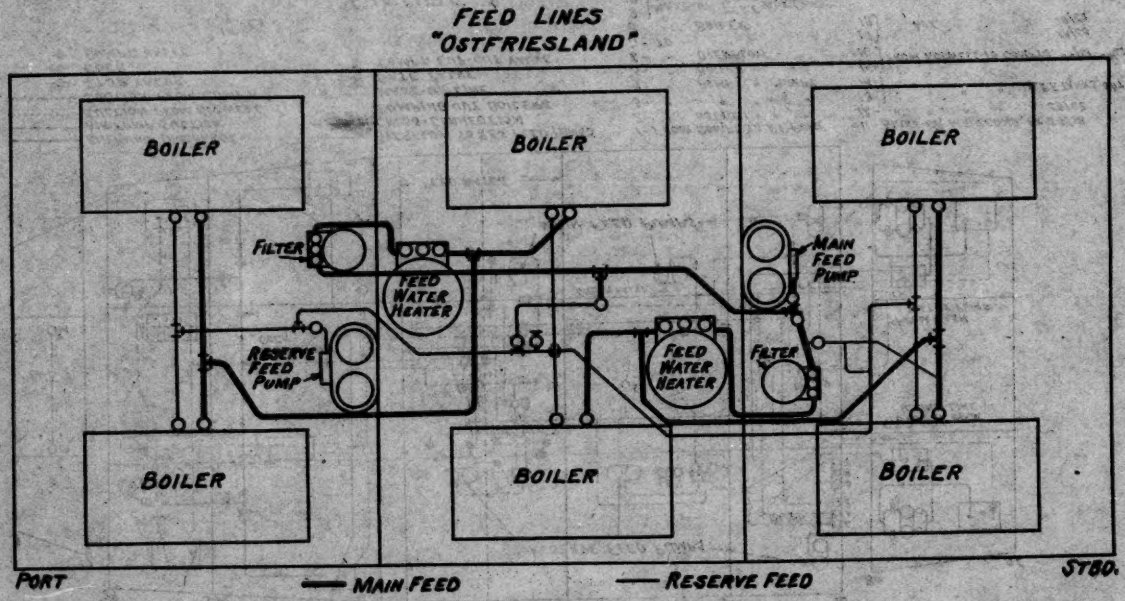
FEED LINES
"OSTFRIESLAND"
BOILER
BOILER
BOILER
FILTER
FEED WATER HEATER
MAIN FEED PUMP
RESERVE FEED PUMP
FEED WATER HEATER
FILTER
BOILER
BOILER
BOILER
PORT
MAIN FEED
RESERVE FEED
STBD.

FIGURE 4

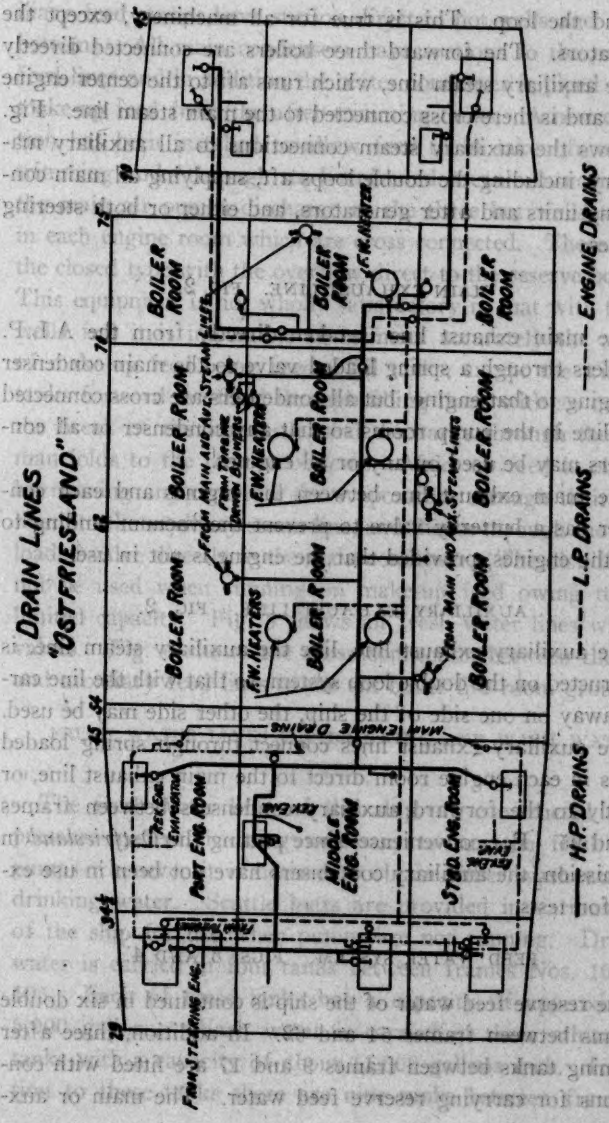
DRAIN LINES
"OSTFRIESLAND"
BOILER ROOM
F.W. HEATERS
MAIN ENGINE DRAINS
PORT ENG. ROOM
MIDDLE ENG. ROOM
STBD. ENG. ROOM
FROM STEERING ENG.
L.P. DRAINS
H.P. DRAINS
ENGINE DRAINS

FIGURE 5

around the loop. This is true for all machinery, except the generators. The forward three boilers are connected directly to the auxiliary steam line, which runs aft to the center engine room and is there cross connected to the main steam line. Fig. 1 shows the auxiliary steam connections to all auxiliary machinery, including the double loops aft, supplying all main condensing units and after generators, and either or both steering engines.

MAIN EXHAUST LINE. FIG. 2.

The main exhaust line is taken directly from the A.L.P. cylinders through a spring loaded valve to the main condenser belonging to that engine; but all condensers are cross connected by a line in the pump rooms so that any condenser or all condensers may be used on any or all engines.

The main exhaust line between the engines and each condenser has a butterfly valve to prevent the vacuum tending to turn the engines, provided that the engine is not in use.

AUXILIARY EXHAUST LINE. FIG. 2.

The auxiliary exhaust line, like the auxiliary steam line, is constructed on the double loop system, so that with the line carried away on one side of the ship, the other side may be used.

The auxiliary exhaust lines connect through spring loaded valves in each engine room direct to the main exhaust line, or directly to the forward auxiliary condensers between frames 90 and 95. For convenience, since putting the *Ostfriesland* in commission, the auxiliary condensers have not been in use except for tests.

FEED WATER SYSTEM. FIGS. 3 AND 4.

The reserve feed water of the ship is contained in six double bottoms between frames 54 and 62. In addition, three after trimming tanks between frames 9 and 17 are fitted with connections for carrying reserve feed water. The main or aux-

iliary feed pumps have suction direct to hot wells and reserve bottoms. All main condensers have suctions to the make-up feed lines and in addition the center condenser is piped to take make-up feed from the after trimming tanks. A new connection has been installed to allow feed to be taken from after trimming tanks through starboard condensers. In normal use the main air pumps discharge to the three hot wells situated in each engine room which are cross connected. These are of the closed type with the overflow direct to the reserve bottoms. This equipment is not wholly satisfactory in that with the hot wells full it is impossible to estimate accurately the amount of make-up feed being used. All tanks, except the trimming tanks forward are filled through filling lines, with an outlet at the break of the forecastle, and discharge through the pump manifolds to the reserve bottoms. Make up feed is obtained by running any or all of the evaporators through their vapor line into the auxiliary steam line, and thence through the spring loaded valve directly to the main condenser. The distillers can not be used when running on make-up feed owing to their limited capacity. Fig. 3 shows all fresh water lines with the valves. Fig. 4 shows the cross connection between the main and auxiliary feed lines in the six boiler fire room groups.

FRESH WATER LINES FOR DRINKING AND WASH WATER PURPOSES.

The fresh water lines of this ship are constructed on the pressure system, it being necessary to run the fresh water pumps whenever it is desired to obtain either wash water or drinking water. Scuttle butts are provided in various parts of the ship for use when pumps are not running. Drinking water is carried in four tanks between frames Nos. 100 and 105. Each of these tanks has a capacity of approximately 5,000 gallons. Wash water is carried in three athwartship tanks with a capacity of about 11,000 gallons each. In addition to these tanks there are nine tanks between frames 70

and 90 which may be used for wash water purposes, six of them having suction to wash water pumps and three which may be used by means of the secondary drain. Wash and drinking water tanks are filled through filling lines on both sides of the ship at the break of the forecastle. The pressure system is supplied by two electric driven fresh water pumps, one for drinking water and one for wash water. These pumps are, however, cross connected and each can be used for either drinking or wash water.

MAIN AND SECONDARY DRAIN LINES.

Main Drain Line.

The main drain line, 21 inches in diameter forms a complete loop through the outboard sides of wing engine rooms, wing fire rooms and carries forward to frame 95. This loop is provided with cut-out valves in each side, the starboard cut-out being in the after fire room and the port cut-out in the middle group of fire rooms. Suction wells are located in each wing fire room, the amidship fire rooms being drained through sluice gates to both wings. There are main drain suctions taken from the athwartship leg of this loop in the middle engine room and forward store rooms at frames 35 and 93, respectively. In addition there are lines leading forward and aft from this main loop forming Tees, and having suction wells in the middle shaft tunnel and after torpedo rooms, forward torpedo rooms and store room spaces. Suction on the main drain may be taken by means of any or all of the after main circulating pumps either through or by-passing the main condensers. In addition, both of the forward auxiliary circulating pumps (electric), may be thrown on, through, or by-passing, forward auxiliary condensers. In addition there are cross connections to the secondary drain in the engine rooms and forward at frame 91. This allows the three fire and bilge pumps to be thrown on to the main drain. All main drain valves are operated from the protective deck through plates located in the deck.

Secondary Drain Line.

The secondary drain line runs amidships nearly the entire length of the ship, from frame 9 to frame 125. Branches from this line lead to various bottoms and compartments.

The secondary drain line is connected through manifolds to each of the three fire and bilge pumps and through two cross connections to the main drain line.

A great many compartments, especially those on the platform deck and above, have natural drain lines with valves to compartments having direct suctions to secondary drains.

COAL STOWAGE. FIGS. 6 AND 7.

The normal coal capacity of the *Ostfriesland* is 2,544.5 tons. This is carried in twenty-two protection bunkers alongside boilers and engine rooms from frames 23 to 90 and in addition ten upper bunkers between frames 23 and 90. There are also two reserve bunkers on the berth deck, normally used for crew space but which may be used for reserve coal. These compartments added to those previously considered and with chutes full give a coal capacity of 2,923.3 tons as follows:

Normal Bunkers	2,460.10 tons.
Reserve Bunkers	394.05 tons.
Permanent chutes	51.26 tons.
Fire room chutes	17.88 tons.
Total	2,923.29 tons.

AUXILIARY STATION.

The auxiliary station covers the machine shop, dynamo rooms, auxiliary condenser rooms, steering engine, anchor engine, refrigerating plant (magazine refrigeration and provisions), air compressors and heating systems.

MACHINE SHOP.

The machine shop, blacksmith and coppersmith shops were originally located on the berth deck amidships between frames 35 and 45. All equipment except one old German lathe and blacksmith's forge had been removed so that the original equipment is not known.

On taking over the *Ostfriesland* it was necessary to install a new shop. This shop was located forward on the port side of the main deck and the following equipment installed.

1—Gap lathe—24 inches × 48 inches × 12 feet (Rahn Larmon).

1—Machine lathe—14 inches (Davis).

1—Universal Milling Machine (Kempsmith).

1—Shaper—12 inches (Davis).

1—Double Emery Grinder (U. S. Electric Tool Co.).

1—Vertical Drill Press, 3 feet radius (Amer. Tool Co.).

1—Sensitive Drill.

All of the above were electric driven, the power being converted from 220 volts (ships circuit) to 80-110 volts, by means of the search light motor generators.

In addition to the above, portable forges, Hauck burners and a complete oxy-acetylene outfit for welding and cutting have proven invaluable and not only handled all the ships work since leaving the Dock Yard at Rosyth but did a great deal of the shop work required in the Dock Yard while undergoing repairs.

DYNAMO ROOMS.

The dynamo rooms, four in number, are located outboard, forward and aft between frames 93 to 100 and 28 to 34 1/2, respectively, those aft being on the upper platform deck while those forward are on the lower platform deck. Each dynamo

room is a watertight compartment and contains two turbo generating units, 8 in all. (See "Electrical Plant" and drawings of steam and exhaust lines.)

AUXILIARY CONDENSING PLANT.

The auxiliary condenser rooms containing the auxiliary condensers with their air and circulating pumps and the fresh water pumps are located in watertight compartments forward on the lowest deck, between frames 90 and 95 outboard of the storerooms. The condensers are of the ordinary surface type. The air pumps are double barreled, single acting and are driven by electric motors (see Electrical Installation), through worm and gear. The water barrel is six inches in diameter with a six inch stroke.

The circulating pumps are electrically driven and connected directly to the motor armature. Runner is approximately 18 inches in diameter. The discharge to condenser is 12 inches in diameter. These pumps have connections to the sea and to the main drain. Condensers have direct connections to the forward dynamo exhaust, the auxiliary exhaust, high and low pressure drain lines (Fig. 5), and make up feed suction from the reserve tanks.

STEERING ENGINE.

The *Ostfriesland* has two rudders and two steering engines. There are two horizontal high pressure cylinders on each engine, controlled by a differential valve, operated through gearing and steering rods from the various steering positions. The cylinders are 8 1/2 inches in diameter by 10 3/4 inches stroke. By a system of clutches and a cross connection of the differential gearing, the following combinations are possible.

(*a*) One engine may operate both rudders.

(*b*) Both engines may operate both rudders.

(*c*) Each engine may operate either rudder.

(*d*) Two engines may operate either rudder.

The steering engines are situated in two watertight compartments one on either side of the ship, separated by a passage way, on the upper platform deck between frames 11 and 15. The clutches for shifting the engines may be operated from either steering engine room or from the passage way between them.

ANCHOR ENGINE.

The anchor engine is located in a watertight compartment on the upper platform deck between frames 103 and 106 and is similar to the steering engine. The engine is a two cylinder, vertical, high pressure engine controlled by a differential valve gear at the engine, or by means of a clutch in the anchor engine room, from deck. The cylinders are 12 inches in diameter by 10 1/4 inches stroke. The engine is connected through clutches and a worm with the windlass and shaft. A brake is provided to allow the anchor to be hoisted by hand in case of failure of the engine, capstans and bars being installed on each deck.

REFRIGERATING PLANT.

The refrigerating machinery is located in the hold just forward of both auxiliary condenser rooms between frames 95 and 100. Communication is through the condenser rooms and a watertight hatch forward to the deck above. Two distinct systems are installed, one a direct CO_2 system to the cooling rooms or cold storage and the other a CO_2-brine system which is used primarily for magazine cooling, though this, the port, system is cross connected to the starboard side and in case of emergency could be used on the cold storage. The compressors are motor driven, vertical, single stage with a 4-inch cylinder and 6-inch stroke, with forced lubrication.

DIRECT SYSTEM.

The CO_2 is fed into the return side of the compressor, passes the compressor, thence to the coil condenser, the cool-

ing water being obtained by means of an electrically driven centrifugal circulating pump with 7-inch runners. The cooling water is obtained from a connection to the sea suction of the auxiliary condenser. From the condenser the CO_2 passes the expansion valve then direct to the coils in the refrigerating room. After passing through the cooling coils, the CO_2 returns through an oil separator to the suction side of the compressor. This is a bad feature. The separator should be on the discharge side of the compressor between compressor and condenser. With the present installation the oil freezes in the coils and blocks the system.

INDIRECT SYSTEM.

After expansion the gas is led to the brine tanks, cooling the brine which is then pumped by means of electric driven circulating pumps through the magazine cooling systems. Brine manifolds are installed in passage ways, each magazine valve being fitted with an independent thermometer for use in regulating magazine temperature.

COOLING BOXES.

It is probable that the Germans used this system simply to convert the cold storage into chill rooms, as there is not sufficient cooling surface to maintain low temperatures. The cooling coils are installed in a box along one side of the cold storage room and air circulated over the tubes and through this box by means of electrically driven fans and having louvres along the end and sides of the room. An exhaust fan on the opposite side assists in securing proper circulation.

TORPEDO AIR COMPRESSORS.

There are four torpedo air compressors, two forward and two aft. They are Whitehead, two stage, Simplex compressors with inverted steam cylinders 2 × 9 1/2 × 8 inches.

These feed airbanks in various torpedo rooms and can also be used on the various Brotherhood torpedo hoists throughout the ship.

HEATING SYSTEM.

The heating system is no different from the type usually employed on our ships but has one peculiar feature in that the vapor from the evaporator may be turned into the heating system and thence through the drains to the feed tanks.

DYNAMOS, ELECTRICAL INSTALLATION.

The Electrical Plant of this vessel consists of eight turbo units with two generators on each shaft, one a 60 kilowatt and the other a 190 kilowatt. The generators were built by Seimens-Schuckert Works at Charlottenburg. They are of the compound interpole type without a compounding shunt, 220 volt, with a total capacity of 1,111 ampères each. The speed of the turbine is 2,000 revolutions per minute. Turbines are similar to Curtis and manufactured by Fried, Krupp. These are designed to work on pressures of from 12 to 16 atmospheres.

There are four dynamo rooms and three distribution rooms, two dynamo rooms and two distribution rooms forward and two dynamo rooms and one distribution room aft. The generators cannot be paralleled, but the load can be regulated by cutting in the various circuits until the maximum load has been reached. Each generator has a positive and negative which supplies the distribution board and a system of four interlocking switches for each circuit.

No circuit breakers or open knife switches are used but each generator and circuit is protected by non-arching fuses.

The dynamo rooms are wired so that either all circuits can be supplied in case the both forward rooms were disabled or that one half the circuits can be supplied in case both after rooms and one forward room were disabled.

WIRE PASSAGE.

A wire passage running from the forward to after distribution room connects with the central station and plotting room, located amidships below the protective deck. All lighting circuits and power circuits from the distribution board supply one side of a watertight double pole, double throw switch which is located in this passage. Each feeder has a tell tale light on the forward and after side of its respective switch so that the operator can tell whether the circuits are being supplied.

LIGHTING FIXTURES.

The lighting fixtures used when ship is darkened consist of box-like metallic frames with side glass. This glass was a very deep blue. The frame was in two pieces and opened by means of two hinges located at top of frame. Each fixture was equipped with a 220 volt 25 watt lamp.

POWER CIRCUITS.

The power circuits are wired with leaded and armored cable similar to that used on board our vessels. The system is installed so that the power can be shifted from the forward to the after dynamo rooms by means of a quick action double pole, double throw, snap switch so that the supply can be shifted without losing power. These switches are located near the motors.

POWER MOTORS.

The general design of motors used throughout is of the shunt, four pole, type with four interpoles. The hand starting panels used are similar to those in our service and consist of an arc of flat contacts fitted with a no voltage release but differ in having no overload release.

The fuses used are of the non-arcing contact type fitted in porcelain with a contact on both ends, one end making contact on the busses which run through the box and the other end to circuit which it supplies.

The stuffing tubes used are similar to those used on board our ships, although in many places where large wires pass through the deck, a kick tube, twice the diameter of the wire is used and concrete poured in so as to make them watertight.

The ice machines, auxiliary condensing plants, fresh water pumps, brine circulators, flushing pumps and jacking motors are all driven by shunt motors of varying horsepower.

SEARCH LIGHTS.

The searchlight voltage was regulated by motor generators, eight in number, which are capable of generating either 60, 80 or 100 volts by regulating a field rheostat in the vicinity of the search light. These searchlight motor generators are now used for the lighting circuits and give very good results. This change was necessitated by the fact that no 220 volt lamps were available, and the first scheme tried, of placing two lights in series gave continual trouble with consequent large lamp expenditures. The motor generators are of the vertical type fitted with roller bearings.

CRANES AND CAPSTANS.

The crane and capstan motors are 60 horsepower, shunt, interpole motors, on the Ward Leonard system, requiring a separate end of one large generator to supply each. The wiring is similar to that of our steering gear and the installation works satisfactorily. The fields of the motor and generator are supplied from the lighting circuits fused to 25 ampères. The brake used with these motors is of the electro-mechanical type but only one disc is used in conjunction with eight bronze studs backed by heavy springs. The brake can be released either by hand or electricity so that the brake can be disen-

gaged without dis-assembling when constant use with a light load is required.

LIGHTING CIRCUITS.

The lighting circuits are fed from a 220 volt source. Armored cable is used throughout. Where feeders are too large, branch junction boxes are used to feed eight way distribution boxes. Four of these boxes are protected by a twenty-five ampère fuse. The feeder toward the end of the line (as its carrying capacity decreases) passes through the distribution box by means of two bus bars insulated with mica and secured by two brass strips which hold them secure.

There are two circuits in every compartment behind armor, arranged so that, in case one circuit fails, adequate illumination is available. Every light is numbered and the fuse which supplies the light can easily be located by the number on the fuse box. This is a decided improvement on our system.

RADIO.

The radio installation was completely removed, nothing remains but a few deck insulators and lead-ins to the main radio room and after battle radio, located near the after conning tower. There were four radio motor generators located below the protective deck, no doubt two for arc and two for spark.

FIRE CONTROL.

All fire control instruments and gyro compass were missing although the ship control instruments were intact.

INTERIOR COMMUNICATIONS.

No voice tube call bell system was installed but a mouth piece and whistle were used in their stead.

The interior communication circuits are supplied from a 220 volt motor-generator, generating 220 volts alternating current, stepped down to 50 volts by means of small transformers.

RUDDER TELEGRAPHS.

Rudder telegraph. Power is derived from a 220 volt alternating current generator, stepped down through a 0.6 KV.A. transformer to 50 volts, 3 to 12 ampères.

The transmitter is located in tiller-room and consists of drum type contact maker, which is operated by means of an endless wire run through pulleys and connected to rudder yoke. Pulleys are so arranged so as to prevent lost motion.

Receivers are located in central station, steering platform, conning tower, engine rooms, turrets, and in after conning tower. They are very similar in construction to the receiver part of the engine telegraph, working on a magnetic principle. They are clock dial type with graduated markings from zero to thirty-five degrees for right or left rudder. When power is off needle falls to hard left rudder position.

ENGINE ROOM TELEGRAPHS.

There are two sets entirely isolated from each other. Both sets are identical in construction and method of operation.

Power is derived from the 220 volt alternating generator, passes through and is stepped down to 50 volts in a 0.3 KV.A. transformer, 1.45 ampères.

The transmitter consists of pedestal dial, one for each engine room, all mounted on the same base, dial face graduated for speed regulation. They are of the combined transmitter and receiver type. In transmitting, say from bridge to engine room operating lever is moved to desired position. Energy is furnished to magnets in identical position in engine room set, attracting magnetic needle to that position. Check is made by moving operating lever in engine room to position of needle, which in turn moves needle of set on bridge, this assuring that signal is understood. A Klaxon is sounded in the engine room by any movement of the bridge telegraph.

REVOLUTION INDICATOR.

This indicator is of the galvanometer type and the transmitter consists of a small, permanent magnet type, generator geared to shaft. As shaft revolves, electro motive force is generated and transmitted to receivers, located in conning tower, central station, engine rooms and number one turret.

The receivers are clock dial type graduated to read in revolutions. As electro motive force is increased by speeding of shaft, the needle of receiver is deflected, the extent of which depends upon the speed of shaft, which by calibration gives the correct number of revolutions on the dial.

FIREROOM TELEGRAPHS.

Power is derived from 220 volt alternating current generator, stepped down through a 0.2 KV.A. transformer, 0.94 ampères. There are two transmitters, one located in middle engine room and one in starboard engine room. A cut-out switch is located in wiring passage which shifts from one to the other.

Transmitters are of iron case watertight construction and signals are sent by means of small notched hand wheel with pointer, for various signals. A bell is connected in parallel and receives an impulse as each notch is passed over, thus calling the attention to signal being made.

Receiver is dial type, magnetic principle and an arrow indicates the signal made. The receiver also has a bell in parallel which rings as the transmitter is moved.

GENERAL REMARKS ON ELECTRICAL INSTALLATION.

There is no mechanical engine telegraph from the bridge to the engine room. If the electric telegraph fails the only resort would be the voice tube communication.

The fuse boxes used for interior communication lighting and power circuits are watertight, large and about as effective as those used in our service. Only the proper size fuse can be

inserted, thereby protecting the circuit from being overloaded. This is assured by fuses of various carrying capacities being made in different sizes.

The entire lighting system is divided into six circuits, no battle circuit was used, and this, I believe, is inferior to our system of darkening ship. Blue light fixtures were located in the various compartments for darkening ship as described above.

All motors are semi-watertight in construction and well ventilated by means of a fan mounted on the shaft. The frames and face plates of the motors are of solid casting and are considered unsatisfactory for making minor repairs.

In many cases when it is necessary to remove the armature the entire apparatus such as pumps, etc., must be broken down. A flanged coupling as used aboard our vessels is a decided advantage.

Circuit breakers and overload releases are not used in connection with any of the apparatus. The absence of these causes unnecessary delays and inconveniences when the main switch board fuse blows.

SPECIAL FEATURES.

The following special features are worth examining with a view of incorporating, if considered desirable, in new construction.

1. Screwed deck plates over all cylinders with tracking on berth deck, allowing pistons to be swung from berth deck, thus decreasing required head room over engines.

2. Setting up gear on piston rod glands. In this gear, reach rods with a hand wheel are brought out to the operating platform. These rods are connected through a worm to gearing around the gland which in turn actuates a thread on the gland allowing the packing to be set up in case of leaks without the use of wrenches. This also acts as a lock.

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"OSTFRIESLAND"

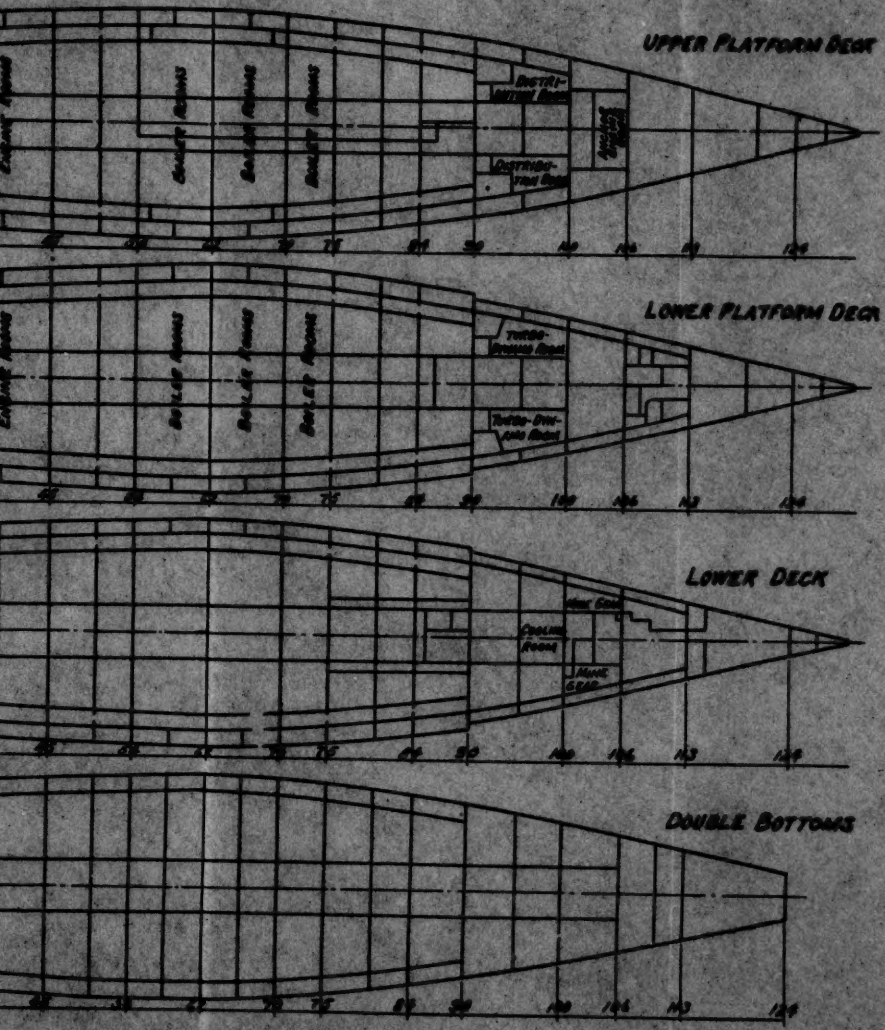
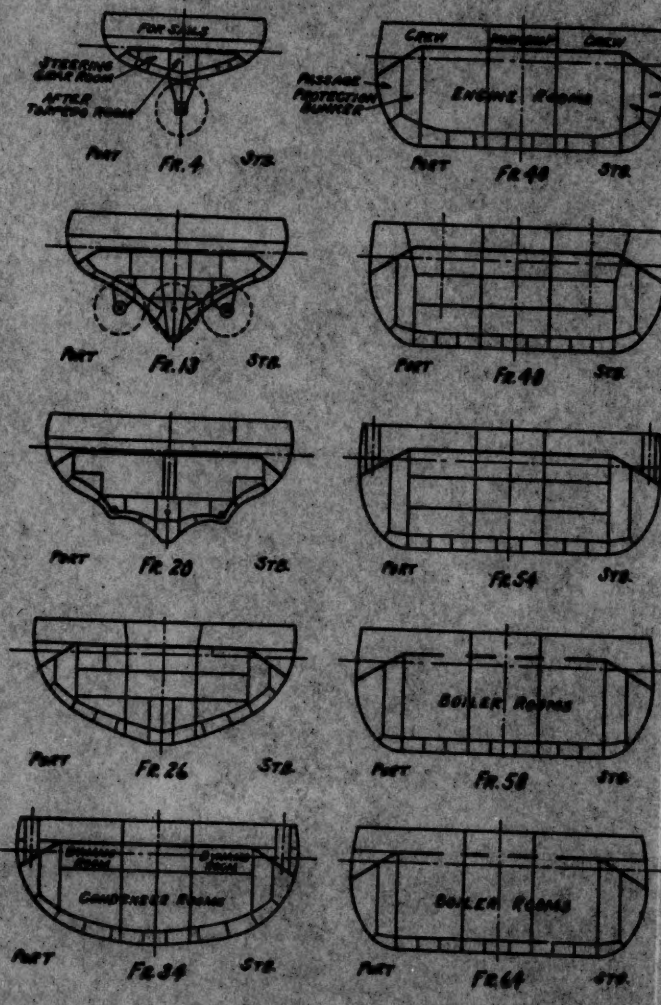


FIGURE 6

"OSTF

AFTER CROSS-SECTIONS



FIG

"OSTFRIESLAND"

FORWARD CROSS-SECTIONS

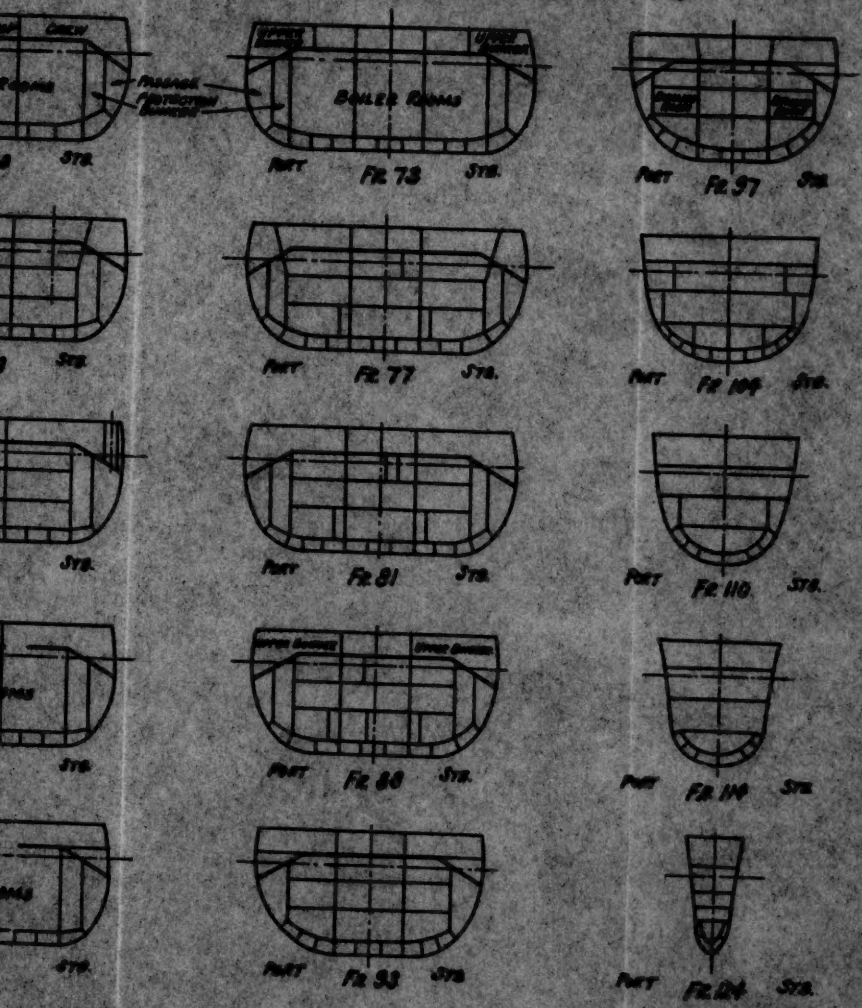


FIGURE 7

3. Cut-outs on wick feed. A lever on the side of the reservoir allows the feed to be cut off immediately on stopping the engines without removing wicks and insures the same regulation of lubrication when the engines are again started.

4. Location and size of feed tanks. The feed tanks are placed at the top of the engine rooms leaving space below for installation of evaporators. The overflow being to the reserve feed tanks insures against loss of feed water to the bilges as is the case in most of our installations.

5. Deck stops and cut-outs. The ratchet gear on these makes them practically fool proof and insures their working in the proper direction. They can be closed but not opened from deck.

6. All go ahead valve motions are controlled by double eccentrics, with the astern between these two. This does away with offset rods and insures proper alignment of valve motion and relieves any strain on the guides. The guides are considerably heavier than usually found on our installations and are of better design, due to the double eccentric. They, however, necessitate an increase in overall length.

7. The engines are fitted with starting valves admitting steam to either side of I.P or L.P pistons, but no by-passes are fitted. This allows the starting of the engine if the H.P. happens to stick on a center but is not as satisfactory as a by-pass.

8. Electric Jacking Engine. This is decidedly more accurate than a steam jacking gear. The control is decidedly quicker than with a throttle. This installation is a decided advantage during overhaul periods when steam is off the ship, as the engine can be jacked from yard power.

9. Coupling bolts on shafts. A starting screw is placed on the after end of the bolt allowing withdrawal without the use of a maul.

10. The double steering engine and two rudders is, I should say, a distinct improvement over our design and gives a 100

percent factor of safety. The control by means of shafts in place of wire is a big improvement on ours.

11. The control of the differential valve of the anchor engine from deck is a great convenience but involves no new question of design.

12. Gage Glass Fittings. The ball and socket arrangement allows removal of fitting and glass together. Spares can be kept fitted in the fire rooms and installed in about thirty seconds.

13. Fire extinguishers in furnaces.

14. Dampers on both front and rear of boilers allowing a more perfect regulation of air through the fire beds.

15. The track system in the bunkers allowing movement of coal from one end of the ship to the other is a decided advantage. The Germans probably used a trip bucket.

16. The chute arrangement from the upper bunkers allowing coal to be fed directly to fire rooms before emptying lower bunkers probably adds considerably to the stability of the ship and requires less trimming.

17. The high location of all pumps in fire rooms relieves the congestion on the floor plates. In addition it adds to the safety of the ship as pumps can be operated on drains long after the fires have been flooded, both through secondary bilge suctions and by suction hose attached directly to the water end of the pump.

18. There should be two additional pumps for use on secondary drain and fire mains. With only three fire and bilge pumps, two of which must be used almost constantly on ash ejectors, maintenance becomes a serious problem.

GENERAL COMMENTS ON CONSTRUCTION.

I should say that the *Ostfriesland* is slightly behind the ships of the U. S. Navy, constructed at the same time, as far as naval engineering is concerned. The workmanship and fin-

ish throughout the department is better than ordinarily found on our ships.

Electrically I should say that the *Ostfriesland* was at least three years in advance of ships of the *Delaware* class. It is in the electrical equipment and installation that the better workmanship and finish is particularly noticeable. The switch boards, distribution rooms and wire tunnels being particularly good. The system of interlocking switches makes the switch board practically fool proof and the entire system is beautifully installed.

Throughout the department are little devices for convenience in working and handling the various machinery.

CONSTRUCTION AND PERSONNEL.

The water tight construction of each separate fire and engine room is, I think, a decided improvement over our ships as far as a protection against sinking, due to either external or internal causes, in fact, it is doubtful if a single torpedo or mine or even two, would sink this ship. I believe this statement is justified by the results of the war. It will be noted that there are seventeen water tight sub-divisions from forward aft, and as will be noted within the engineering spaces, these compartments are further divided by two fore and aft bulkheads into three separate water tight compartments. This same construction is carried out in other parts from frames 23 to 106.

This sub-division without means of communication, except "up and over," would require a considerably greater complement than carried on one of our ships of the same displacement, both of officers and men. No data are available as to the number of officers and men carried, beyond the statement, (unconfirmed), in a British publication that the crew was 1,400 men.

THE OPERATION OF BLOWERS IN PARALLEL FOR FORCED DRAFT IN NAVAL SERVICE.

By M. C. Stuart, Associate*, and Arthur H. Senner.

The quantity of air required in a fire room is definitely fixed by the amount and quality of fuel to be burned for the production of the maximum required capacity. The pressure required in the fire room, which is the head against which the fan or blower operates, is not so definitely known as it depends upon the combined resistance of the air registers, boiler and uptakes in the case of an oil-burning installation. In a coal-burning installation the problem is more complex because of the variable resistance of the fuel bed, in addition to the resistance of the grate, boiler and uptakes.

Originally, one fan was provided for a fire room. As capacities grew, two, three or four fans were installed for a single room. With two or more fans operating in parallel in a fire room, it is obvious that they must all operate at a common head which is the pressure of the fire room. However, the capacities delivered by the several fans are not equal unless the fans are operating at exactly the same speeds and have the same fan characteristics. If one fan slows down, there will result a decrease in quantity of air delivered by that fan. This decrease in quantity delivered by the slower fan will not be in direct proportion to the decrease in speed, but will usually be much greater, depending entirely upon the shape of the quantity-head characteristic of the fan. Under certain conditions which are not at all unusual in prac-

*Professor of Mechanical and Marine Engineering, Post Graduate School, U. S. Naval Academy, Annapolis, Md.

tice, it is entirely possible for a decrease in speed of one of the fans, amounting to only two or three hundred revolutions per minute, to result in the quantity of air delivered by the slower fan to be reduced to zero. Further than this a considerable quantity of air may be faced backward through the slower fan.

An investigation has recently been conducted at the U. S. Naval Engineering Experiment Station, Annapolis, Md., upon the operation of fans in parallel.

OBJECT OF INVESTIGATION.

The principal objects of this investigation were as follows:

(*a*) To observe the action of two similar fans operating in parallel at different speeds and discharging air against the same head.

(*b*) To obtain negative quantity characteristic, *i. e.* to determine the relations between quantity passing through fan and pressure head maintained by fan, when air is being forced backwards through the slower of the two fans.

(*c*) To compare the combined efficiencies when operating fans at different speeds with efficiencies when operating fans at equal speeds, under the same draft requirements in each case.

(*d*) To study the relative advantages of the flat and the steep characteristic types of forced draft blowers.

DESCRIPTION OF FANS.

The two similar motor driven forced draft blowers used for this test were obtained from the U. S. S. *Nevada*. The fans which were manufactured by the B. F. Sturtevant Co. are of the No. 7, single width, multi-vane type with double air inlet, and forward tipped blades. The diameters of the fans are 29 inches.

DESCRIPTION OF APPARATUS AND METHOD OF TEST.

On Fig. 1 is shown a diagrammatic sketch of the general arrangement for test. With this test arrangement a line of circular duct was led from the discharge of each fan into a common cylindrical chamber, 10 feet in diameter and 10 feet long. This air chamber corresponds in the test to the fire room in forced draft practice. Referring to the plan view on Fig. 1, the following description is explanatory of the general arrangement of apparatus and method of test.

A venturi-meter was placed in each line of duct leading from the fans to the air chamber. Static pressures were read at the fan outlets and before the air chamber in each duct by means of draft gages. Four orifices of one square foot area each were placed in the end of the air chamber. These orifices, circular in section and having well rounded entrances, were designed so that each of them could be blanked off, thus duplicating varying draft requirements as on shipboard. The static pressure in the air chamber was measured by means of a differential gage connected, as is shown on Fig. 1, to the head of a cylindrical appendage on the top of the air chamber, this being an ideal point for pressure determination, because of the absence of eddies and effects of velocity head. The other leg of the differential gage which is used for determination of the static pressure in air chamber was connected to an impact tube. By traversing the mouths of the orifices with this impact tube when air was flowing, there was seen to be no difference in pressure between the air chamber static and the velocity head at the orifice mouths.

When for the purpose of the investigation there was any difference in the speeds of the two fans, fan "A" was always the slower fan and in some cases this caused a reversal of the direction of the air in the duct attached to fan "A." For this reason the venturi-meter in this duct was so arranged as to indicate the quantity of this reversed air.

The temperature of the air in the ducts was determined as shown on Fig. 1 in the duct leading from fan "A." For this purpose an exposed bulb thermometer was used and installed so as to project well into the duct. Hygrometric data were gotten by the use of a motor driven wet and dry bulb outfit placed adjacent to the fan suctions.

For a knowledge of the power required to drive the blowers, data of the electrical input were taken during the runs and these together with a knowledge of the various losses which was determined by a series of motor loss runs permitted the net input to the fans to be determined.

DESCRIPTION OF RUNS.

A total of 30 runs was made, and the data and results of these runs are tabulated in two sections on Fig. 2. The upper section of Fig. 2 gives the data and the results of the fan delivering into the 30-inch duct, *i. e.*, fan "A" shown on Fig. 1. In the lower section of Fig. 2 are tabulated the data and results of the fan delivering into the 40-inch duct. The first fifteen items in each section of the table are identical, these items comprising the general data which apply to both blowers when operating together and also the air chamber data and the readings taken to determine the flow through the orifices. From an analysis of the first 6 runs it is seen that all the orifices on the end of the air chamber were blanked. Fan "B" attached to the 40-inch duct was in each of these runs the faster fan and obviously with the orifices on the air chamber blanked, all the air delivered by the faster fan was forced backward through the slower fan. During runs 7 to 19, inclusive, orifices were opened on the air chamber, but due to the great difference in speed of the fans in each of these runs a certain quantity of air was forced backward through fan "A" on the 30-inch duct. During these runs the quantity of air passing through the orifices plus the quan-

tity forced back through the slower fan equaled the quantity of air delivered through the 40-inch duct by fan "B." On runs 19 to 30, inclusive, although as before fan "A" is the slower fan, with the differences of speeds maintained on these runs and the relatively large numbers of orifices open on the fan house, a positive direction of flow prevailed in each duct. During these runs the quantity of air delivered by fan "A" plus the quantity delivered by fan "B" equaled the quantity of air passing through the orifices in the air chamber, the agreement being in most cases within two per cent. The source of items in Fig. 1 is given in Appendix 1.

RESULTS OF TESTS.

The data and results of the tests are presented in graphical form in the curves of Figs. 3 to 10, inclusive. On Fig. 3 is plotted the constant speed, quantity-head characteristic of either fan. The pressure head is that measured in the duct at the fan outlet. These results have been reduced to standard air conditions and 900 revolutions per minute. The characteristic has also been plotted in the negative air quantity region; the data for this part of the curve are obtained from runs Nos. 1 to 19, inclusive, on fan "A," during which runs the air was forced backward through fan "A," although the fan itself was driven in a positive direction. While it has been realized that a fan has a definite negative quantity characteristic, it is believed that this is the first instance in which this characteristic has been determined experimentally. As will be shown later, this characteristic is of vital importance in studying the operation of fans in parallel. On Fig. 4 are plotted two characteristics of quantity and head at different speeds in both the positive and negative quantity regions. The combined characteristic is also drawn which shows the net effect of running two fans at different speeds and discharging at each instant against the same head. The combined characteristic is gotten by adding algebraically the

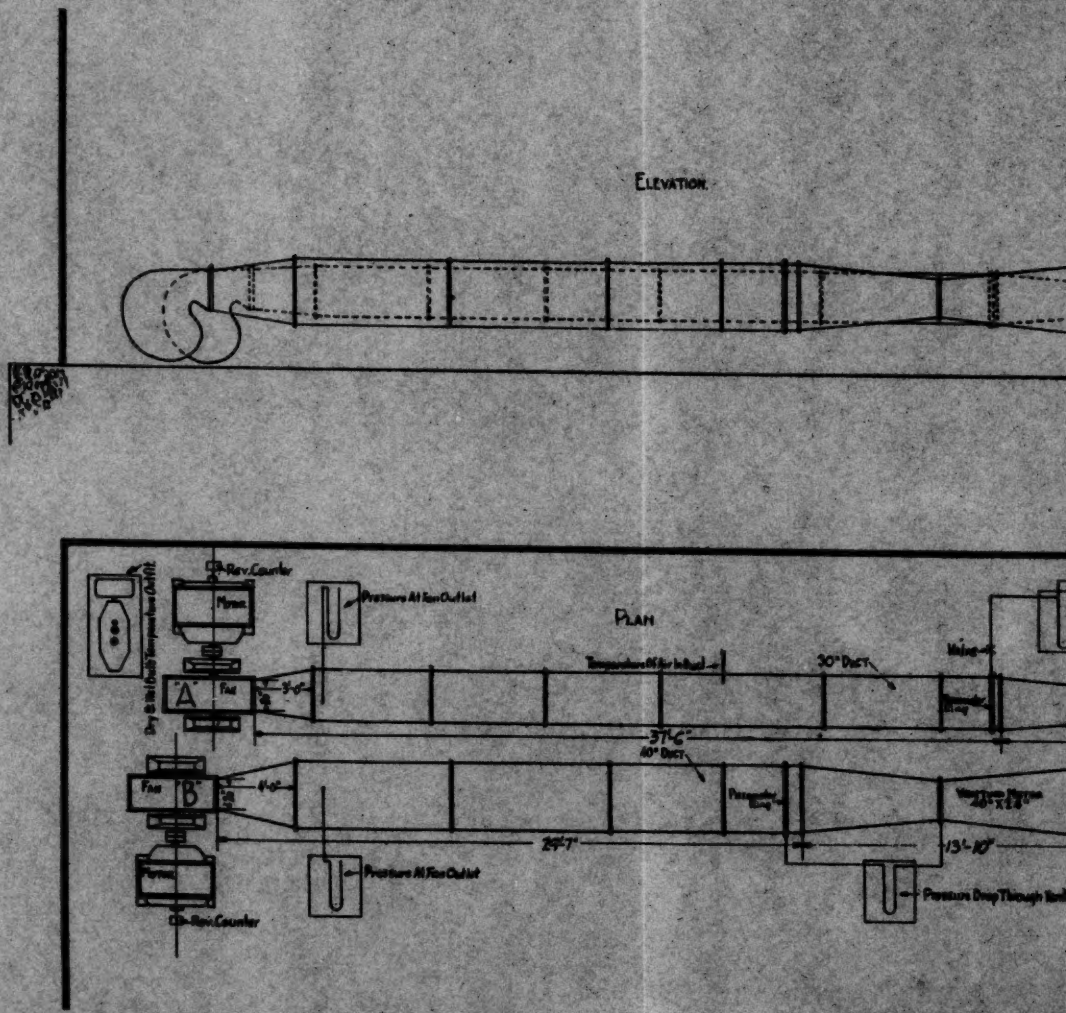
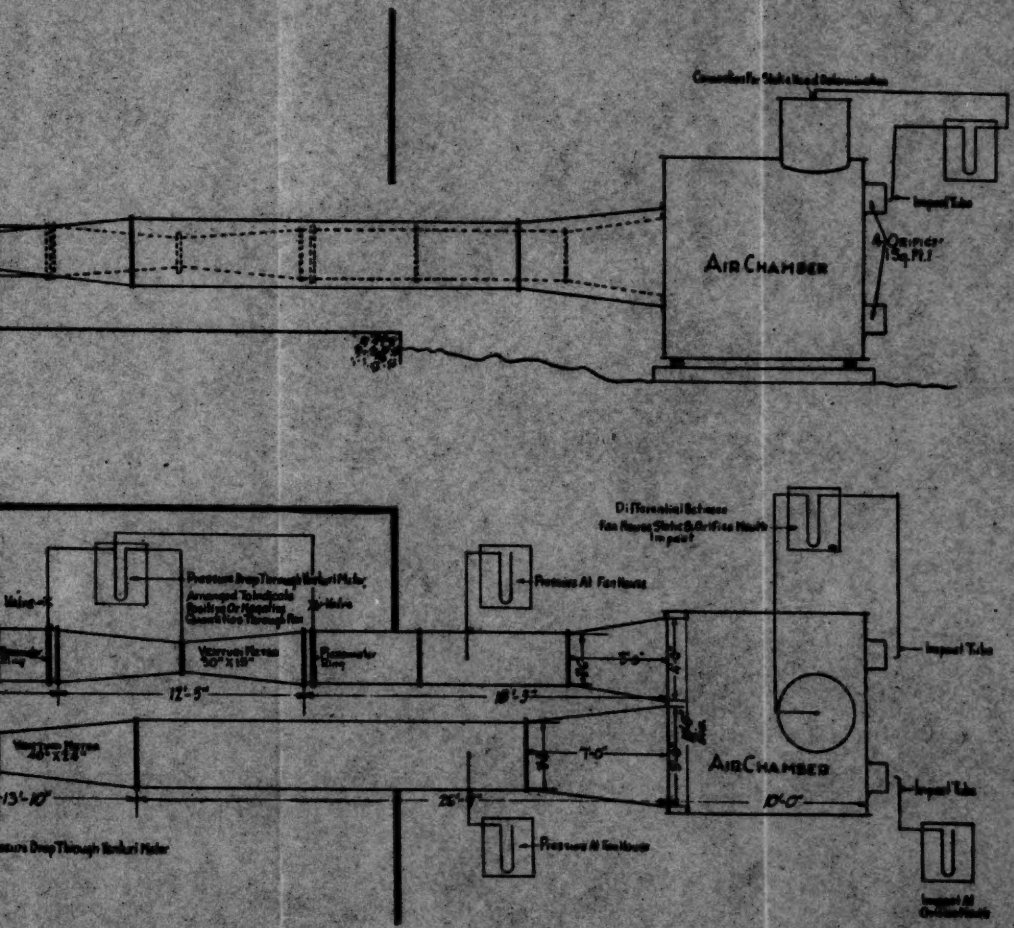


Fig. 1.—Test Arrange



TEST ARRANGEMENT.

TABLE I

TEST OF BLADES OF

FIG. 2

FIG. 2.—TABLE, DATA AN

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ERS OPERATING IN PARALLEL.
FIG. 2
BLE, DATA AND RESULTS.

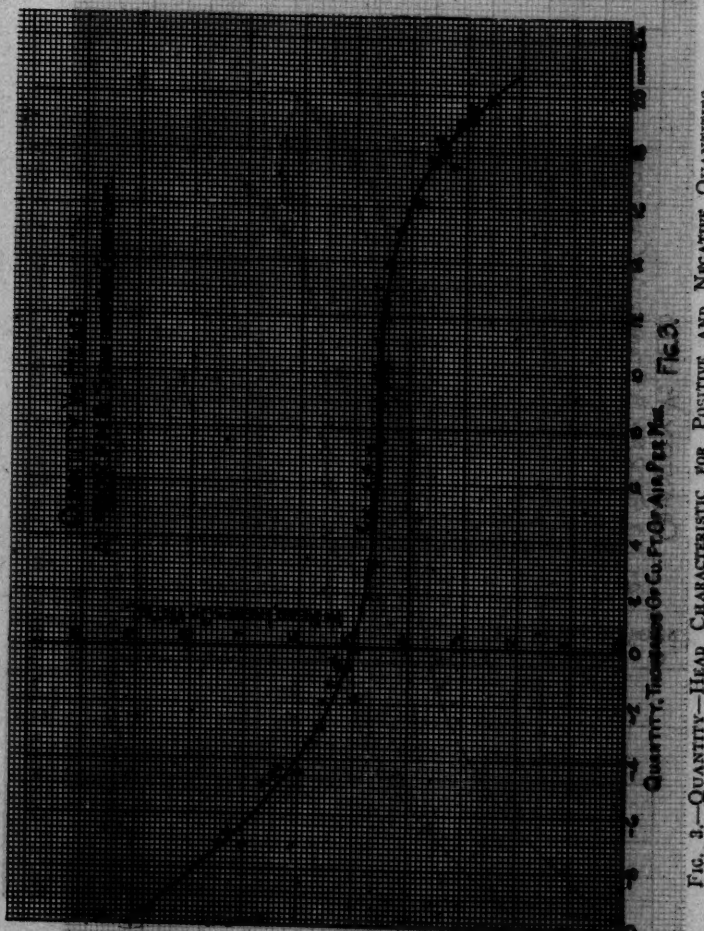


FIG. 3.—QUANTITY—HEAD CHARACTERISTIC FOR POSITIVE AND NEGATIVE QUANTITIES.

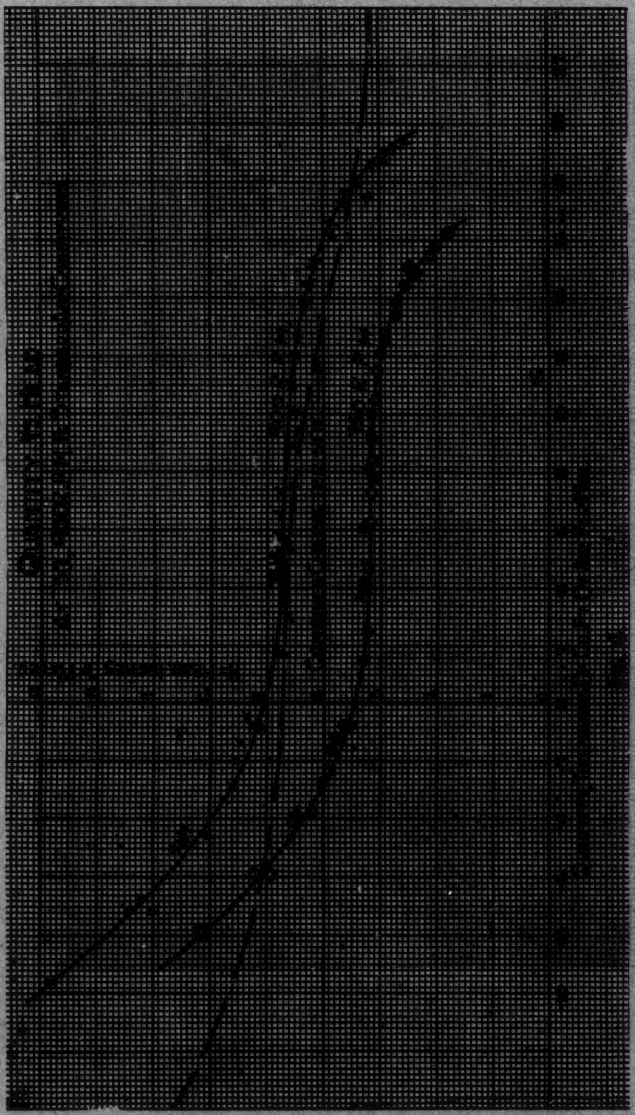


FIG. 4.—COMBINED CHARACTERISTIC OF TWO SIMILAR FANS AT DIFFERENT SPEEDS.

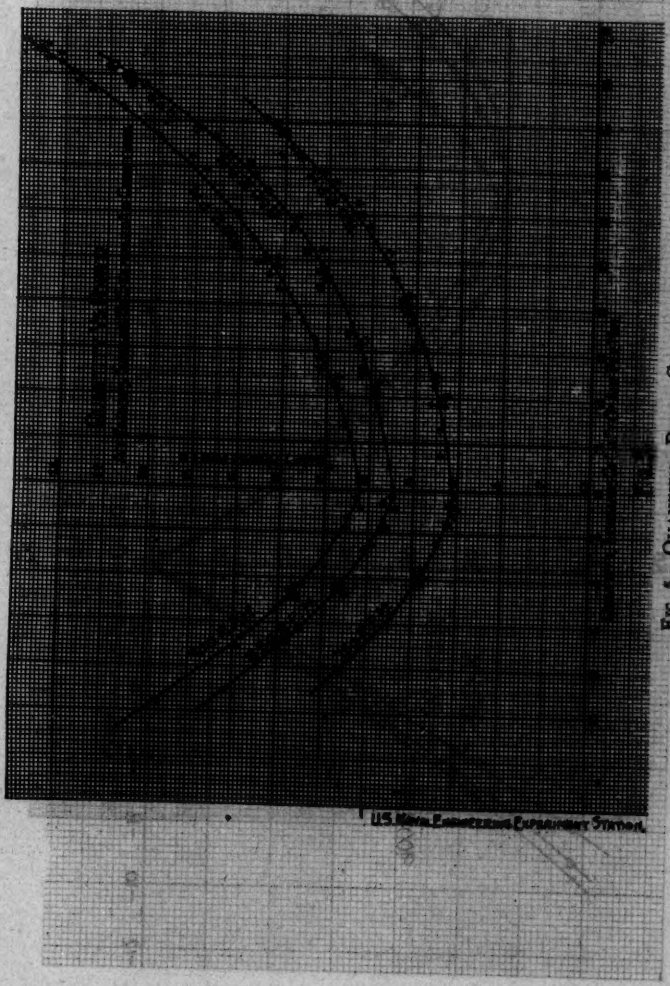


FIG. 5.—QUANTITY—POWER CHARACTERISTICS.

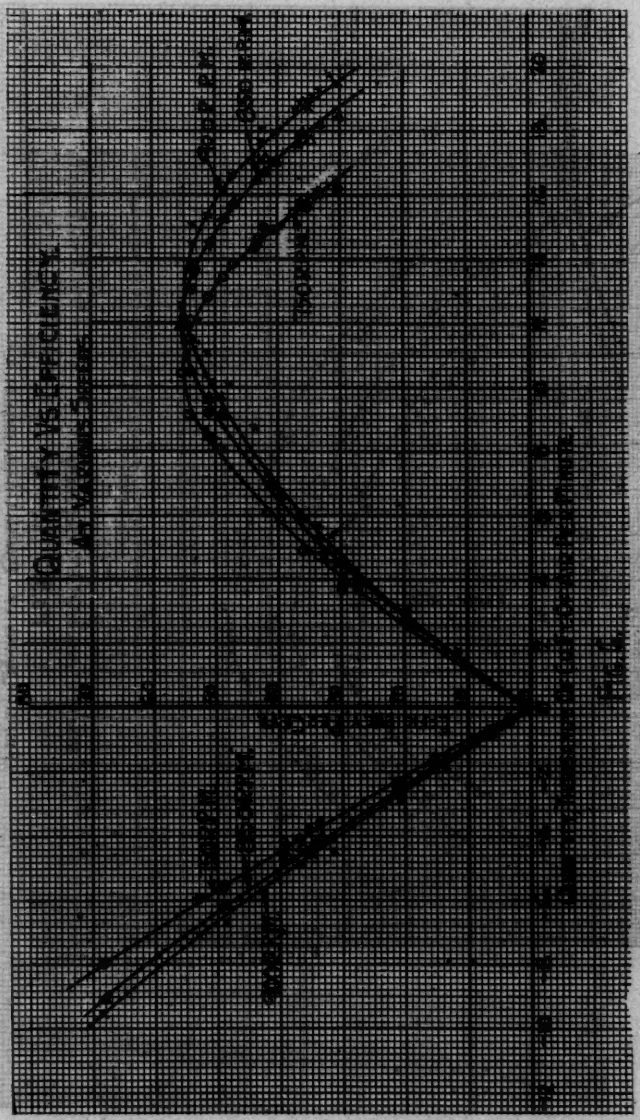


FIG. 6.—QUANTITY—EFFICIENCY CHARACTERISTICS.

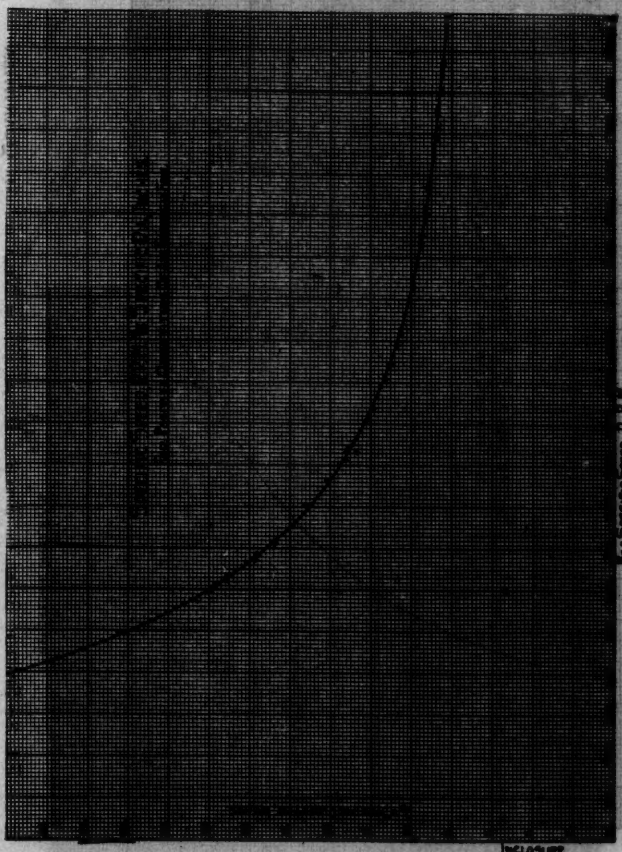


FIG. 7.—SPECIFIC SPEED VS. SPECIFIC DIAMETER FOR POSITIVE AIR QUANTITIES.

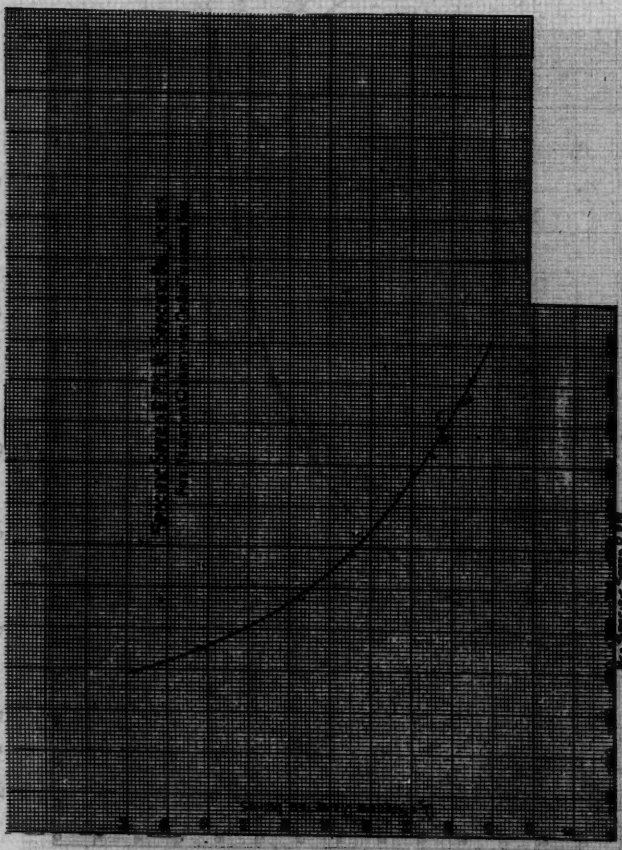


Fig. 8.—Specific Speed vs. Specific Diameter for Negative Air Quantities.

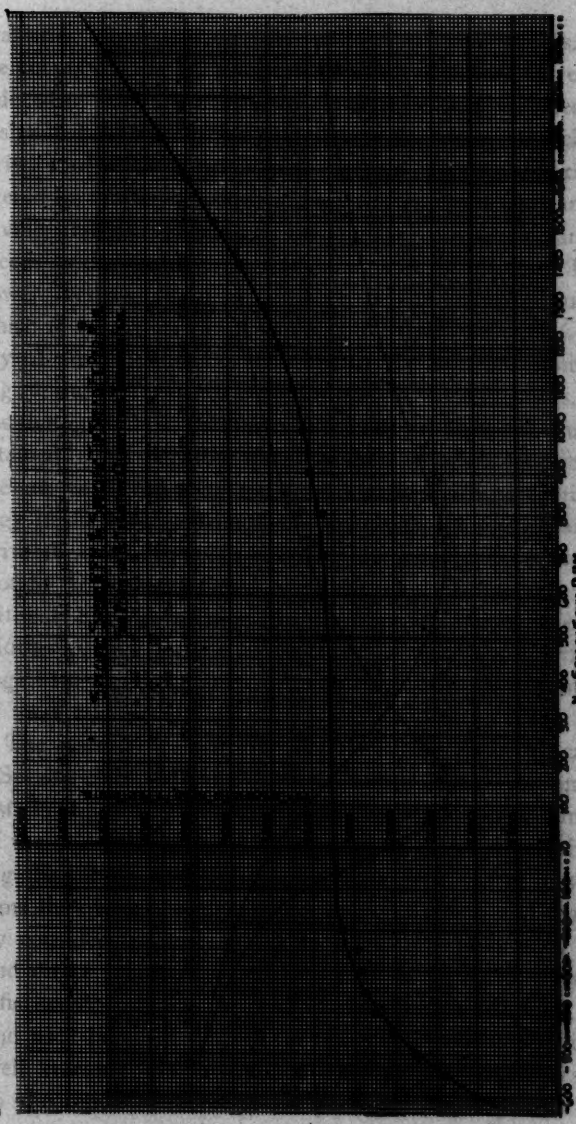


FIG. 9.—SPECIFIC SPEED VS. SPECIFIC TIP SPEED FOR POSITIVE AND NEGATIVE QUANTITIES.

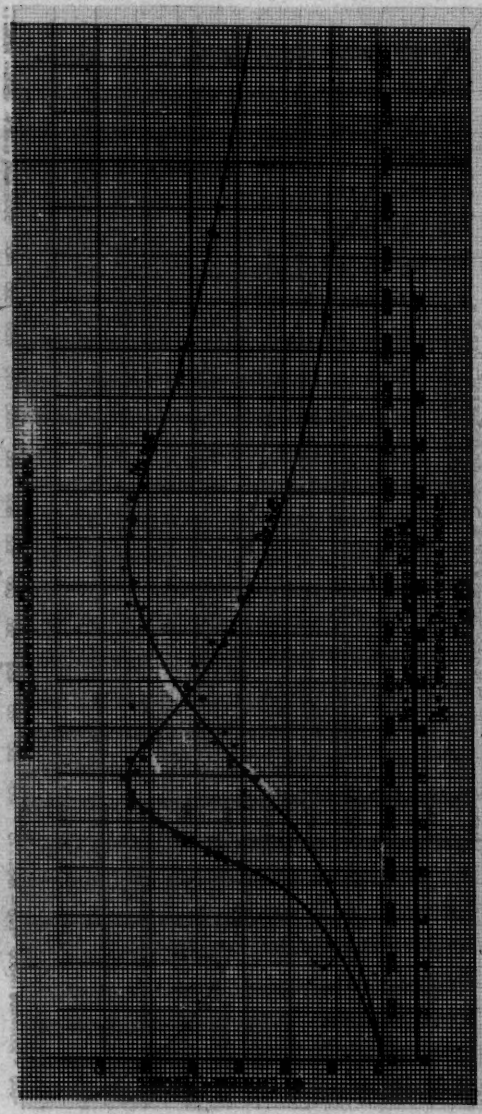


FIG. 10.—SPECIFIC SPEED VS. EFFICIENCY AND SPECIFIC DIAMETER VS. EFFICIENCY FOR POSITIVE AIR QUANTITIES.

quantities of air delivered by each fan at given heads. On the curves of Fig. 4, the performances as plotted have been reduced to standard density of air and the standard speeds as designated on the curves. On Fig. 5 are plotted the characteristics of both positive and negative quantity of air delivered by the fan *vs.* shaft horsepower required, the variables having first been reduced to the standard air density and the speeds as designated. As would be expected the shaft horsepower increases with an increase in the negative quantity which is forced backward through the fan. Curves of quantity of air delivered *vs.* efficiency of the fans are plotted on Fig. 6, the performance being reduced to various speeds. For positive quantity a maximum efficiency of 55.3 per cent was attained. For negative quantity there is no true efficiency, the curves representing merely the ratio of the potential energy in air forced through the fan to the power required to drive the fan. Figs. 7, 8, 9 and 10 give curves which are plotted from specific fan data of the fans. The article "Centrifugal Fan Calculation by the Specific Speed Method," (JOURNAL OF AMERICAN SOCIETY OF NAVAL ENGINEERS, page 613, August, 1916), gives in detail the method and uses of these calculations.

The essential element of what the writer choses to call the "Specific Speed Method" of performing fan calculations consists in expressing the diameter and speed of fans as functions of the quantity and head. The value of this method of treating the subject rests on the fact that in nearly all fan problems the quantity and head are known factors, and therefore by considering these as the independent variables, a simple and direct solution of problems may be obtained. The specific speed formulae derived in the above mentioned article and used herein are based on two groups of laws which are well known to fan manufacturers. These laws are subject to theoretical demonstration, and have been proven to be

substantially correct by numerous tests of fans of various types and sizes. The first group of laws pertains to a given fan operating on a system with a fixed external restriction. If the speed (revolutions per minute) of the fan be changed, without changing any of the external restriction against which the fan operates, the following laws are effective:

(*a*) The volume of air discharged by the fan will vary as the speed.

(*b*) The pressure maintained by the fan will vary as the square of the speed.

(*c*) The power required by the fan will vary as the cube of the speed.

(*d*) The efficiency of the fan will remain constant.

A second group of laws may be stated which will cover the change in size of a fan of a given design. In this case consider a fan of a certain design and size, operating at a given speed, and on an external system with a given restriction. The external restriction may be replaced by what is known as an "equivalent orifice," that is, an orifice at the outlet or inlet of the fan, of such a size that the performance of the fan is the same as when operating against the actual system. There may be constructed a fan of the same design as the one considered, but of different size, such that all dimensions of the new fan, including the "equivalent orifice," are in same exact proportion to the corresponding dimensions of the given fan.

This fan may be designated as a "geometrically similar fan." If the geometrically similar fan be run at the same speed (revolutions per minute) as the original fan, the following laws connect the performance of the fans:

(*e*) The volume discharged will vary as the cube of the ratio of the diameter of the fans.

(*f*) The pressure maintained will vary as the square of the ratio of the diameters of the fans.

(*g*) The power required will vary as the fifth power of the ratio of the diameter of the fans.

(*h*) The efficiency will remain constant.

DERIVATION OF FORMULAE.

Let

D = Maximum diameter at tip of blade, inches.

h = Static head, inches of water, at standard air density.

N = Revolutions per minute, or speed.

Q = Discharge, thousands of cubic feet per minute.

P = Power required—horsepower.

e = Efficiency.

Laws (*a*), (*b*), (*c*) and (*d*) may be expressed as follows:

$$Q = C_1 N \quad (1)$$

$$h = C_2 N^2 \quad (2)$$

$$P = C_3 N^3 \quad (3)$$

e = constant. D = constant.

Laws (*e*), (*f*) and (*g*) and (*h*) may be expressed as follows:

$$Q = C_4 D^4 \quad (4)$$

$$h = C_5 D^2 \quad (5)$$

$$P = C_6 D^5 \quad (6)$$

e = constant. N = constant.

From reductions of equations (1), (2), (4) and (5), there results:

$$N = C_7 \frac{h^{\frac{1}{2}}}{Q^1}$$

For the special case in which $D = 1$ and $Q = 1$, $N = C_7$; or, C_7 is the speed of a fan required to produce one inch static pressure and one thousand cubic feet of air per minute. We may now call C_7 the "specific speed" of the fan, and designate it by the symbol N_s, so that

$$N = N_s \frac{h^{\frac{1}{2}}}{Q^{\frac{1}{2}}} \quad (7)$$

and

$$N_s = N \frac{Q^{\frac{1}{2}}}{h^{\frac{1}{2}}} \quad (8)$$

It should be borne in mind at this point that equations (7) and (8) make no mention of the diameter of the fan required to meet these conditions. The variation of diameter, as affected by quantity and head, for constant efficiency, and independent of speed, is determined by a reduction of equations (1), (2), (4) and (5), and there results:

$$D = C_s \frac{Q^{\frac{1}{2}}}{h^{\frac{1}{2}}}.$$

For the special case in which $Q = 1$ and $h = 1$, $D = C_s$, or C_s is the diameter of a fan required to produce one inch static pressure, and one thousand cubic feet of air per minute. We may call C_s the "specific diameter" of the fan, and designate it by D_s; then

$$D = D_s \frac{Q^{\frac{1}{2}}}{h^{\frac{1}{2}}} \quad (9)$$

and

$$D_s = D \frac{h^{\frac{1}{2}}}{Q^{\frac{1}{2}}} \quad (10)$$

DEFINITIONS.

We may now define the "specific fan" of a certain type as a fan which is geometrically similar to a given fan of the type, and has such a diameter, D_s, and runs at such a speed, N_s, as to deliver one thousand cubic feet of air per minute at one inch static head at any given efficiency.

SIGNIFICANCE AND USE OF N_s AND D_s.

If for any fan, operating at a certain efficiency, the head, quantity, speed and diameter are known, the specific speed of the fan at that efficiency may be determined from equation (8),

$$N_s = N \frac{Q^{\frac{1}{2}}}{h^{\frac{3}{4}}}$$

and the specific diameter at that efficiency may be determined from equation (10),

$$D_s = D \frac{h^{\frac{1}{4}}}{Q^{\frac{1}{2}}}$$

Conversely, if the specific speed and specific diameter of a certain fan or type of fan be known at any efficiency, the actual speed and diameter of a geometrically similar fan required to produce any desired quantity and head, at the same efficiency may be determined from the formulae (7) and (9).

Figs. 7 and 8 give curves of specific speed, revolutions per minute, *vs.* specific diameter, inches, of the fans for both positive and negative quantities of air through fan, *i. e.* for the fan discharging air and also when air was being forced back through the fan. Fig. 9 is the curve of specific speed, revolutions per minute, *vs.* specific tip speed, feet per minute, for positive and negative quantities of air through fan. Specific speed and specific diameter are plotted against efficiency for positive and negative quantities, Fig. 10.

Now, in order to satisfy objects (*a*), (*b*) and (*c*) of this investigation as given under "Object of Test" the following problem was worked out as illustrative of an actual operation example: It is assumed that two fans are to deliver 24,000 cubic feet of air per minute when operating in parallel in a fire room. The required fire room pressure is 4.5 inches and therefore the head against which these fans must deliver this quantity of air is 4.5 inches of water regardless of the load

distribution between the two fans. The requirements are exactly met when the fans are running at equal speeds of 900 revolutions per minute, as seen from Fig. 3, however, doubling the quantity at 4.5 inches since two similar fans are to operate in parallel. A decrease in the speed of one fan will necessitate an increase in the speed of the other to maintain the requirements. The curves which are drawn in dashed lines on Fig. 11 show the respective speeds of the faster and slower fans corresponding to various differences in speeds of the two fans. Also since the total quantity under any conditions of speeds of the two fans must equal 24,000 cubic feet of air per minute, the full line curves show the quantities of air to be delivered by each fan corresponding to various differences in speeds. The total quantity of air delivered by the fans together is represented as a horizontal full line at 24,000 cubic feet of air per minute.

At zero difference in speeds of the two fans the curves of quantities and speeds intersect at ordinates of 12,000 cubic feet of air per minute for each fan and 900 revolutions per minute for each fan. At a difference in speed of 270 revolutions per minute or a speed of 855 for the slower fan and 1,125 for the faster, the entire quantity is delivered by the faster fan. For greater differences in speed, a negative quantity will flow backward through the slower fan as shown by the region designated "A." The complete characteristics for any type of fan, with both positive and negative quantities having been determined, calculations based on these characteristics are possible, which will determine the exact performance of two or more of these fans operating in parallel in a fire room. Calculations are made by the "Specific Speed" method, explained briefly above. The "Specific Speed" method is largely a short cut application of what are generally known by fan designers as the "One, Two, Three" Laws.

The effect of speed difference on power consumed by two fans operating in parallel is shown on Fig. 12. It is seen

FIG. 11.—EFFECT OF SPEED DIFFERENCE ON QUANTITIES DELIVERED BY TWO FANS OPERATING IN PARALLEL.

that with both fans running at the same speed the total power required is a minimum of 31.25 horsepower, and this function increases with an increase in the speed difference of the two fans. There are also drawn on Fig. 12 curves showing the division of power between the two fans. It is noted that the total air horsepower is constant as represented by the horizontal dashed line. On Fig. 12 is also shown clearly the extent of falling off of combined efficiency of the forced draft outfit when certain requirements are fulfilled by two fans operating at different speeds. The maximum efficiency attained is at the point of zero difference in speed of the two fans.

"RELATIVE MERITS" OF "FLAT CHARACTERISTIC" AND "STEEP CHARACTERISTIC" FANS FOR FORCED DRAFT SERVICE ON BOARD SHIP.

Figs. 13 and 14 have been supplied for the purpose of determining and comparing the effects which naval service conditions would probably have on parallel operation of the two types of fans having the above mentioned characteristics. Fig. 13 represents the performance of a fan having a flat characteristic. The two full-line curves represent the characteristics at two speeds of 1,400 revolutions per minute and 1,500 revolutions per minute. Referring to the curve of 1,500 revolutions per minute it is seen that for a change of only one inch of water pressure head, the quantity increases from zero to 40,000 cubic feet of air per minute. Thus it is seen from this that the quantity delivered changes from zero to a value which is approximately 75 per cent of the maximum capacity of the fan at the given speed, with an accompanying change of only one inch of water static head. Although the flat characteristic fan has great flexibility as to quantity delivered, it permits of only a slight variation in fire room pressure. With this very limited variation in the pressure head with which the flat characteristic fan may operate

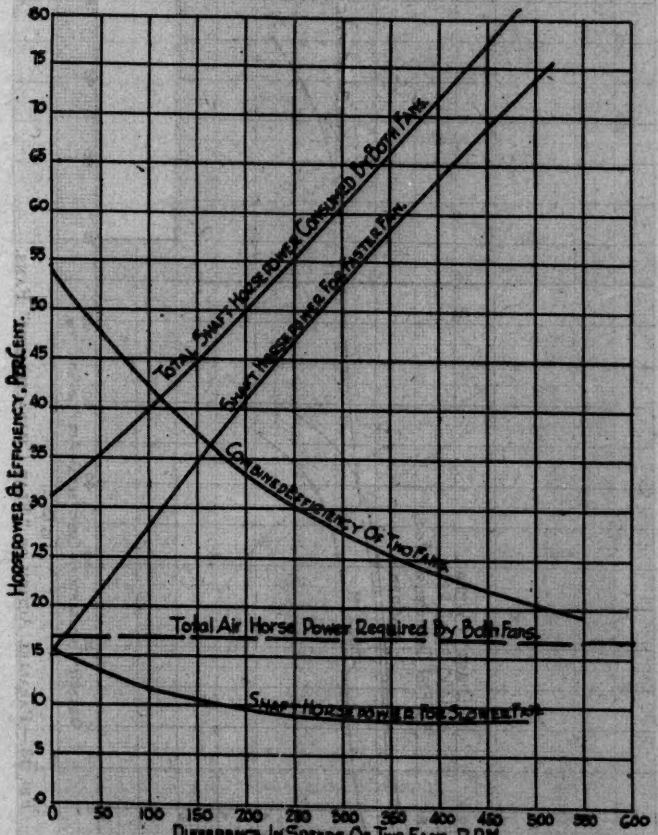

Horsepower & Efficiency, Per Cent.
Total Shaft Horsepower Consumed By Both Fans.
Shaft Horsepower For Faster Fan.
Combined Efficiency Of Two Fans.
Total Air Horse Power Required By Both Fans.
Shaft Horsepower For Slower Fan.
Difference In Speeds Of Two Fans, R.P.M.
Effect Of Speed Difference On Power Consumed By Two Fans Operating In Parallel.
Total Quantity Of Air Delivered By Two Fans = 24,000 Cu. Ft. Per Min.
Head = 4.5 Inches Water.
At Standard Air Conditions.
Fig. 12.

FIG. 12.—EFFECT OF SPEED DIFFERENCE ON POWER CONSUMED BY TWO FANS OPERATING IN PARALLEL.

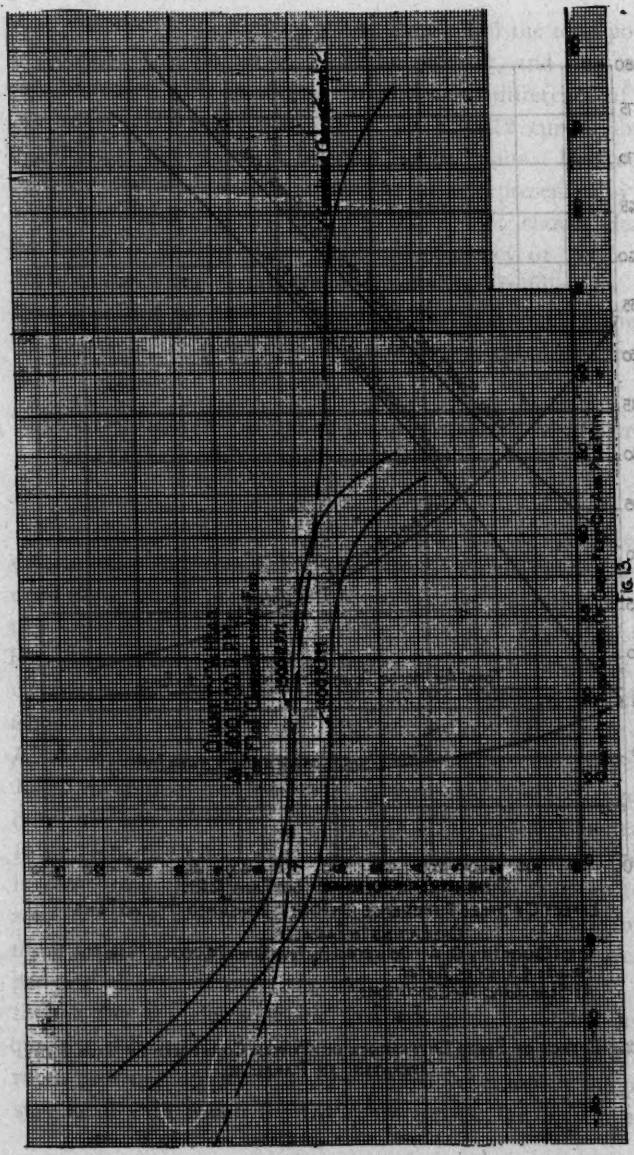


FIG. 13.—PARALLEL ACTION OF "FLAT CHARACTERISTIC" FANS.

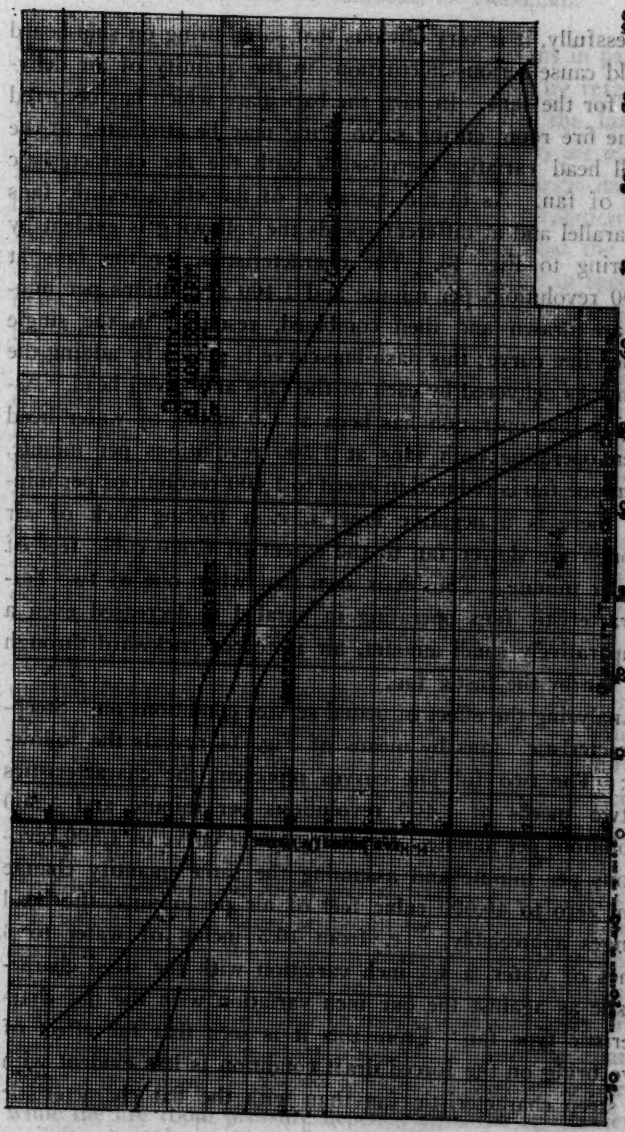


FIG. 14.—PARALLEL ACTION OF "STEEP CHARACTERISTIC" FANS.

successfully, it is very obvious that salvo firing on ship-board would cause serious fluctuations in the quantity of air delivered for the fans. In fact, the back flare which has occurred in the fire room during salvo firing may be attributed to the small head variation permissible with the flat characteristic type of fan. As to the operation of flat characteristic fans in parallel and at different speeds the following is evident by referring to Fig. 13. The characteristics for the fans at 1,500 revolutions per minute and 1,400 revolutions per minute are drawn and then combined, resulting in the single dashed-line curve; this dash-line curve is gotten by adding the quantities delivered by each of the fans at a given head. Assuming that operation has been at 7.0 inches of water head when operating both fans at 1,500 revolutions per minute, when one fan is reduced in speed to 1,400 revolutions per minute, there is a negative flow, *i. e.* a forcing back of air through the slower fan to the extent of 6,000 cubic feet of air per minute. Thus it is seen that when one of two flat-characteristic fans operating in parallel is decreased even a comparatively small amount, air is forced backward through this fan by the faster fan.

Analyzing the effect of actual service conditions on "Steep-characteristic" fans by means of Fig. 14 reveals the following: The two full-line curves represent the characteristics at two speeds of 1,400 revolutions per minute and 1,500 revolutions per minute. Referring to the curve of 1,500 revolutions per minute and assuming the same quantity change from zero to 40,000 cubic feet of air per minute, the head changes appreciably, *i. e.* from 10.5 inches of water to 6 inches of water, a 4.5 inch variation with the steep characteristic as against the one inch variation with the flat characteristic type fan. From this it is seen that the effect of salvo firing on the forced draft condition is less evident with the steep characteristic fan than with the flat characteristic

fan. For the operation of steep characteristic fans in parallel and at different speeds, the following is evident by referring to Fig. 14. As before the characteristics for the fans at 1,500 revolutions per minute and 1,400 revolutions per minute are drawn and then combined resulting in the single dashed-line curve. With a difference of speed of 100 revolutions per minute as in the previous example it is seen that the fans combine to greater advantage with this difference in speed in that there is no reversal of air through the slower fan until the fire room pressure exceeds 9 inches of water.

In forced draft practice with stoker fired boilers, the steep characteristic type of fan is standard equipment for the following reason: With fires of normal thickness and condition, the fan will operate at a point of relative low head on the characteristic. If the resistance of the fire bed increases due to clinkers, or for any other cause, the point of operation of the fan moves up the steep characteristic with only a small decrease in quantity, but a considerable increase in head. This increase in head assists in loosening up the fire and forcing the required amount of air through the fire, thus maintaining the rate of steaming. With a flat characteristic fan, an increase in the resistance of the fire bed will cause a large decrease in quantity of air. On board an oil burning ship the firing of the salvo has a momentary effect in increasing the pressure analogous to the thickening of the fires in a stoker. For this reason alone the steep characteristic fan should be preferred in the naval service. With a flat characteristic there is a large variation in quantity and a small variation in head. With a steep characteristic the reverse is true. In designing a fan for an oil burning installation the quantity of air required may be much more accurately predetermined than the fire room pressure, because the quantity depends only upon the known quantity of fuel to be burned, while the fire room pressure depends upon the resistances of

intake, boiler and uptake, which are not so definitely known. With a steep characteristic fan, a variation in the actual pressure required from the computed pressure will cause less variation in the quantity. An apparent advantage of the flat characteristic is the large variation in quantity possible, but this is not necessary because the required maximum quantity of air may be accurately computed, and any type of fan must be designed for this maximum. Smaller quantities for reduced load may be obtained by reducing the speed.

The question of rotational speed, tip speed, efficiency and noise must also be considered. The higher rotational speeds of the steep characteristic fans are conducive to better turbine economies for direct drive. However, the higher tip speeds of the steep characteristics require better materials and stouter construction. The highest reported efficiencies have been obtained with the steep characteristic types. Little is known regarding the relative noise of the several types, but it is believed that noise is not a function of the type, but depends upon design and construction in each case. In general the low efficiency fans produce the most noise.

CONCLUSION.

From this investigation the following conclusions are drawn:

(*e*) Fans operating in parallel should be run at the same speed because relatively small differences in speed cause an unequal division of the load between the fans in such a manner as to result in a greater total shaft horsepower than would be required to produce the same draft conditions with the fans running at equal speeds.

(*f*) At differences of speeds which are likely to occur in practice there may result a reversal of the direction of air through the slower fan, *i. e.* a certain quantity of air may be forced back through it by the faster fan.

(*g*) It is preferable to install only one fan in a fire room or provide some means for driving all fans in the fire room at the same speed.

(*h*) Steep characteristic fans operate better in parallel than flat characteristic fans. The steep characteristic type of fan is preferred also because it provides a wide variation in head to cover the increase of pressure due to salvo firing and the uncertainty in estimating the fire room pressure.

APPENDIX NO. 1.

SOURCE OF ITEMS IN TABLE 1, TEST OF FANS OPERATING IN PARALLEL.

Item.

1. Reference number. For reference.
2. Date. From records taken during run.
3. Number of orifices open. From records taken during run.
4. Barometric pressure, inches mercury. From mercury barometer, readings taken during run corrected for scale error and reduced to a mercury density of 0.4912 pound per cubic inch at 32 degrees Fahr.
5. Room temperature, degrees Fahr. From thermometer readings taken during run corrected for calibration error.
6. Wet bulb temperature, degrees Fahr. From thermometer readings taken during run corrected for calibration error.
7. Density of air in room pounds per cubic foot. From Taylor's Tables for Densities of Air, corresponding to items (4), (5) and (6).
8. Actual static pressure in fan house, inches water. From readings of draft gages taken during run.
9. Temperature of air in fan house, degrees Fahr. From thermometer readings taken during run corrected for calibration error.
10. Density of air in fan house, pounds per cubic foot.

$$\text{Item (7)} \times \frac{\text{Item (8)} \times 0.0732 + \text{Item (4)}.}{\text{Item (4)}.}$$

11. Orifice coefficient. Value of 0.99 assumed for orifices used on test.
12. Total orifice surface open, square feet. Item (3) × Area of each orifice.
13. Ratio of standard air density to actual air density. 0.07492÷ item (7).
14. Air discharged, cubic feet per minute.

From the relations:

$Q = 0.99 \times 60\,AV$

$V = \sqrt{2g}\ \sqrt{ha}$

$ha\,da = hw\,dw$

$ha = hw\,\frac{dw}{da}$

Q = cubic feet of air per minute discharged.
A = area of orifices, square feet.
V = velocity through orifice, feet per second.
g = 32.174.
ha = head of air, feet, at orifice.
hw = head of water, feet, at orifice, for standard air density = item (8) divided by 12 inches in 1 foot.
Hw = head of water at orifice for standard air density, inches = item (8).
Dw = density of water, pounds per cubic foot = 62.30.
da = density of air, pounds per cubic foot = 0.075
then

$$Q = 0.99 \times 60\,A\,\sqrt{2g}\,\sqrt{\frac{62.3}{0.075 \times 12}}\,\sqrt{Hw}$$

$$Q = 3966 \times A\,\sqrt{Hw} = 3966 \times \text{Item (12)} \times \sqrt{\text{Item (8)}}$$

15. Duration of run, minutes. From time records taken during run.
16. Revolutions per minute. From readings taken during run.
17. Static pressure up stream section, inches water. From readings of draft gages taken during run.
18. Temperature at up stream section, degrees Fahr. Item (9).
19. Density of air at up stream section, pounds per cubic foot.

$$\text{Item (7)} \times \frac{\text{Item (17)} \times 0.0732 + \text{Item (4)}.}{\text{Item (4)}.}$$

20. Differential pressure at Venturi Meter, inches water. From readings of draft gages taken during run.
21. Air discharged under suction conditions, pounds per minute. From the formula:

$$W = 60\,\sqrt{P_1\,d_1} \times A_2\,F\,\left(\frac{P_2}{P_1}\right), \text{ in which}$$

W = item (21).
P_1 = [item (4) plus (item (17) multplied by 0.0732)] multplied by 70.718 pounds per square foot equivalent to one inch of mercury.
d_1 = item (19)

A_2 = area of throat section, square feet.
$P_2 = P_1$ minus (item 20 multiplied by 5.1917).
5.1917 = pounds per square foot equivalent to one inch of water.

$$F\,\frac{(P_2)}{(P_1)} = \text{function of } \frac{P_2}{P_1} \text{ as given in theoretical Venturi}$$

Air Meter formula; file at the Engineering Experiment Station, Drs. No. 829 and 830. A factor of 0.98 was applied to the Venturi Meter formula.

22. Air discharged under suction conditions, cubic feet per minute. Item (21) divided by Item (7).
23. Static pressure at fan outlet, inches water. From readings of draft gages taken during run.
24. Air horsepower under actual air conditions and test speed. Item (22) multiplied by item (23) and by 5.1917, and divided by 33,000.
25. Shaft horsepower at test speed and actual air conditions = Electrical Input (armature current × voltage) minus (stray power loss corresponding to speed + copper loss in armature corresponding to armature current).
26. Air discharged by fan, cubic feet per minute, corrected to 900 revolutions per minute. Item (22) multplied by $\frac{900}{\text{item (16)}}$
27. Static pressure at fan outlet, corrected to standard air density and to 900 revolutions per minute, inches of water.

$$\text{Item (23) multiplied by } \frac{0.07492}{\text{item (7)}} \text{ and by } \left[\frac{900}{\text{item (16)}}\right]^2$$

28. Air horsepower corrected to standard air density and to 900 revolutions per minute.

$$\text{Item (24) multiplied by } \frac{0.07492}{\text{item (7)}} \text{ and by } \left[\frac{900}{\text{item (16)}}\right]^3$$

29. Shaft horsepower corrected to standard air density and to 900 revolutions per minute. Item (28) multiplied by 100 and divided by item (38).
30. Air discharged by fan, cubic feet per minute, corrected to 850 revolutions per minute. Item (22) multiplied by $\frac{850}{\text{item (16)}}$
31. Static pressure at fan outlet, corrected to standard air density and to 850 revolutions per minute, inches of water.

$$\text{Item (23) multiplied by } \frac{0.07492}{\text{item (7)}} \text{ and by } \left[\frac{850}{\text{item (16)}}\right]^2$$

32. Air horsepower corrected to standard air density and to 850 revolutions per minute.

Item (24) multiplied by $\frac{0.07492}{\text{item (7)}}$ and by $\left[\frac{850}{\text{item (16)}}\right]^3$

33. Shaft horsepower corrected to standard air density and to 850 revolutions per minute. Item (32) multiplied by 100 and divided by item (38).

34. Air discharged by fan, cubic feet per minute, corrected to 750 revolutions per minute. Item (22) multiplied by $\frac{750}{\text{item (16)}}$

35. Static pressure at fan outlet, corrected to standard air density and to 750 revolutions per minute, inches of water.

Item (23) multiplied by $\frac{0.07492}{\text{item (7)}}$ and by $\left[\frac{750}{\text{item (16)}}\right]^2$

36. Air horsepower corrected to standard air density and to 750 revolutions per minute.

Item (24) multiplied by $\frac{0.07492}{\text{item (7)}}$ and by $\left[\frac{750}{\text{item (16)}}\right]^3$

37. Shaft horsepower corrected to standard air density and to 750 revolutions per minute. Item (36) multiplied by 100 and divided by item (38).

38. Fan efficiency, per cent. Item (24) divided by item (25) and multiplied by 100.

39. Specific speed of fan, revolutions per minute.
From the formula:

$$N_s = N\frac{Q^{\frac{1}{2}}}{h^{\frac{3}{4}}}, \text{ in which}$$

N_s = specific speed, item 39.
N = 900 revolutions per minute.
Q = item (26) divided by 1,000.
h = item (27).

40. Specific diameter of fan, inches.
From the formula:

$$D_s = D\frac{h^{\frac{1}{4}}}{Q^{\frac{1}{2}}}, \text{ in which}$$

D_s = specific diameter, item (40).
D = maximum tip diameter of fan = 29 inches.
h = item (27) and Q = item (26) divided by 1,000.

U. S. S. *TRINITY.*

(EMERGENCY FLEET CORPORATION OIL TANKER NO. 1661).

DESCRIPTION AND TRIALS.

By Henderson B. Gregory, Associate.

The *Trinity* is a single screw oil tanker fitted with geared turbines and designed for a speed of about 10.5 knots, when the main turbines are developing about 2,800 shaft horsepower. She is the last of eight oil tankers contracted for, under date of October 10, 1918, with the Newport News Shipbuilding & Dry Dock Co. and the Navy Department, on behalf of the U. S. Shipping Board Emergency Fleet Corporation.

Under the terms of the contract the price of the hull and machinery was based upon an estimated cost of $2,200,000.00, plus or minus the cost of authorized changes, the contractors to receive a fixed profit of $220,000.00; this profit to be augmented, in the event of the actual cost being less than the estimated cost or authorized revision thereof, by one-third the amount saved.

The hull and machinery are in general accord with the Rules of the American Bureau of Shipping for highest classification, and the U. S. Steamboat Inspection Rules for sea-going vessels. The Navy Department also inspected all work.

The keel was laid November 10, 1919, and the vessel was launched July 3, 1920.

GENERAL DESCRIPTION OF HULL.

The hull is of the following principal dimensions:

Length over all, feet and inches	477–10
between perpendiculars, feet and inches	463–3
on load-water line, feet and inches	462–10
Beam, extreme, feet and inches	60–2⅝
on load-water line, feet and inches	60–0
moulded, feet and inches	60–0
Mean designed draught, feet and inches	26–2
Displacement on designed draught, tons	16,785
per inch on load-water line, tons	57.9
Area of immersed midship section at designed draught, square feet	1,551
of load-water line plane at designed draught, square feet.	24,318
Wetted surface at designed draught, square feet	46,000
Coefficient of fineness, block	0.812
midship section	0.988
load-water line	0.873

The vessel is a single screw, steel steamship, with straight stem, elliptical stern and with flat sheer amidships. It is rigged with two masts and one smoke pipe. It is of the shelter-deck type, with complete steel shelter, upper and main decks, except that the upper and main decks are omitted in way of the oil tank expansion trunks and the machinery space.

The longitudinal system of framing and scantlings is followed throughout.

The propelling machinery is located in the after end of the hold, and a screen bulkhead separates the engine and boiler rooms. Immediately abaft the machinery compartment is the after peak tank. Forward of the boiler room and separated therefrom by a cofferdam, are the fuel oil bunker tanks, of 63,000 cubic feet capacity.

Reserve feed water is carried in tanks under the machinery space, and there as a ballast tank beneath the fuel oil bunkers.

The amidship hold is divided into nine tanks, of about 450,000 cubic feet total capacity, for carrying oil in bulk. The tanks are provided with center-line bulkhead extending to the

shelter deck, dividing them into port and starboard compartments, and there are expansion trunks between the main and shelter decks for the full length of the tanks. The wing spaces, between the main and upper decks in way of the main oil tanks, are divided into five compartments, port and starboard, fitted up as summer oil tanks. The total capacity of these tanks is 43,000 cubic feet. There is a pump room between oil tanks Nos. 5 and 6, and a cofferdam forward of tank No. 1, between tanks Nos. 3 and 4, and between tank No. 9 and the fuel oil bunker tanks.

The following are located in the forward hold: a pump room, cargo space, fuel oil or ballast tanks, chain lockers and the fore peak tank.

Aft on the main deck are located the cold storage compartments, fresh water tanks and storage space. Forward are cargo space and stores.

The upper deck aft is fitted as crew's quarters. The sick bay is located on this deck on the starboard side of the engine hatch. Forward are crew's quarters, prison, carpenter shop, lamp room, emergency generator room, paint room and windlass engine.

Aft on the shelter deck is a deck house for the steering gear, with gun platform on top of the deck house. A similar gun platform is provided in the bow over the windlass. No guns are mounted.

The crew's mess is located in a deck house abreast of the engine hatch, port side, on the shelter deck, with spacious galley on center line abaft the engine hatch. The corresponding deck house on the starboard side of the engine hatch contains the general mess pantry, stores, laundry, and engineer's office.

The radio room is on top of the after deck house.

Forward is a double tier deck house containing the officers' quarters. It is raised 42 inches clear of the shelter deck. On

top of this deck house are the wheel house, chart room and bridges.

The tops of all deck houses and gun platforms are connected by fore-and-aft bridges.

LIFE BOATS, ETC.

The following life boats and life rafts are carried in skid-beams on top of the after deck houses, except the whale boats, which are carried on the forward deck house:

No.	*Type.*	*Capacity each.*
4	26-ft. Metallic life boats	50 persons
2	24-ft. Whale boats	23 persons
1	24-ft. Motor boat	
1	Racine life raft	24 persons
2	Life buoy rafts	25 persons

All boats are swung in Norton sheath screw davits.

DECK MACHINERY.

Windlass.—A 14-inch × 12-inch, double engine, Hyde anchor windlass, with four gypsy heads, is located on the shelter deck forward; the engine is below on the upper deck. Patent anchors are carried, which are stowed in the hawse pipes.

Deck Winches.—Three deck winches are provided; they are all of the Hyde Windlass Company's design. The bow and midship winches have two 8-inch × 10-inch steam cylinders; the stern winch, which is of greater power, has two 9-inch × 14-inch steam cylinders. All winches have two gypsy heads.

Steering Engine.—The steering engine and gear are located in a deck house aft on the shelter deck. It is of the Brown Steam Tiller type, as manufactured by the Hyde Windlass Co. The steam cylinders are 9-inch × 12-inch.

Ammunition Hoists.—Four small Lidgerwood ammunition hoists are provided, two for each gun. They are driven by G. E. Co. motors. The ammunition is carried in small magazines in the forward and after holds.

CARGO OIL PIPING.

The cargo oil suction system consists of two 11-inch steel pipe lines, leading aft from the pump room, one on each side of the center line bulkhead, for draining tanks, 6 to 9, inclusive. Four similar lines lead forward, two for tanks 1, 2 and 3, and two for tanks 4 and 5. Each tank connects to its main through a 9-inch angle valve fitted with bell mouth carried down to near the bottom of the tank. A master gate valve is fitted in the suction main at the transverse bulkhead nearest the pump room of each tank served. All valves are operated from the shelter deck. Valves are arranged that the pumps may draw from any tank and discharge to any other tank.

A 16-inch gate valve, operated from the shelter deck, is fitted on the center-line bulkhead between each pair of main cargo tanks.

The summer tanks are drained by 6-inch pipes. Four 6-inch filling pipes, two port and two starboard, terminating on the shelter deck, are provided for these tanks; they connect to the 6-inch drain mains.

Two 11-inch risers are fitted forward, from the suction mains to the shelter deck, for filling tanks 1, 2 and 3, and two similar risers aft for tanks 6 to 9, inclusive. Tanks 4 and 5 are filled through connections on the 11-inch discharge mains at the pump room hatch, port and starboard. Each filling connection terminates at the deck with an 11-inch gate valve and 11-inch × 8-inch × 8-inch Y-casting with flanged ends. Eight-inch × 6-inch flanged reducers are provided to suit 6-inch U. S. Navy standard oil hose.

Cargo oil is discharged through two 11-inch connections in the pump room, leading to the 11-inch cross-connection on the shelter deck and the discharge mains on the upper deck, port and starboard. These mains are 11 inches diameter, extending aft along the upper deck from the pump room hatch for about 112 feet, where they rise to the shelter deck and are car-

ried aft full size for a short distance and then reduced to 6 inches, continuing to the after end of the deck house abreast of the engine room. Deck discharge connections are taken off these mains. Forward of the pump room hatch the mains are 8 inches diameter for a distance of about 60 feet, where they branch into two 6-inch connections on each side of the vessel, one rising abruptly to the shelter deck and the other extending forward about 75 feet before rising to the shelter deck. All deck connections are flanged to suit 6-inch U. S. Navy standard oil hose.

The cargo tanks are flooded through two 10-inch sea valves in the pump room, either direct or through the pumps, and are pumped overboard via the shelter deck cross-connection. Four portable sections of 8-inch pipe of sufficient length to extend from the discharge outlets to the ship's side are provided for pumping overboard.

The forward fuel oil or ballast tanks are served by a fuel oil transfer pump located in the forward pump room. These tanks are provided with 6-inch deck filling connections, 5-inch suctions and a 4-inch discharge to the fuel oil transfer line and deck, the latter provided with a portable section of piping extending to the ship's side for overboard discharge.

All oil tanks are provided with vents, steam fire-extinguishing connections and steam heating coils.

DESCRIPTION OF MACHINERY.

The main propelling machinery, consisting of turbines and reduction gear, driving a single screw, scotch boilers, etc., is located in a common compartment in the after hold.

Main Turbines.—The main turbines are of the Curtis type as built by the Newport News Shipbuilding & Dry Dock Co. They are designed to develop about 2,800 S.H.P., with 220 pounds steam pressure at the H.P. turbine, when driving the vessel at the designed speed of 10.5 knots.

There are two turbines, a high pressure and a low pressure, each fitted with an ahead and a reverse element in the same casing.

The H.P. turbine has one two-bucket and five single-bucket ahead stages and one three-bucket reverse stage; a diaphragm separates the ahead and reverse stages. The moving buckets, of non-corrosive material, are carried on forged steel wheels securely keyed to the turbine shaft. The casing is of cast iron, and divided into stages by cast iron diaphragms split horizontally at the shaft and carrying steel nozzles cast in the diaphragms. The first stage ahead and the reverse nozzles are of bronze and of the expanding type. The first ahead stage has eleven nozzles arranged in three groups, one of seven nozzles and two* of two nozzles each, the latter are controlled by valves in the steam chest. The reverse stage has eight nozzles, none fitted with control valves.

The L.P. ahead turbine is of the drum type, with alternate rows of moving and stationary blades, fourteen stages in all. The drum is of forged steel carried on cast steel disks, securely keyed to the turbine shaft. Other parts are of the same material as in the case of the H.P. turbine. There is a three-bucket reverse wheel carried on the same shaft as the ahead drum. The reverse element has twenty-four nozzles.

The rotors are carried in suitable bearings arranged at each end of each turbine. Where the shafts pass through the turbine casings there are fitted the usual labyrinth packing glands.

Each turbine is fitted with a Kingsbury thrust bearing at the forward end to take the steam thrust.

The turbines are installed abreast, the H.P. starboard and the L.P. port, and connected to the reduction gear pinions by flexible couplings.

The turbine data is given in Table I.

* One group of two nozzles permanently blanked off after trials.

Control and Reversing Gear.—The turbines are controlled by a twin-throttle valve, which admits steam to the ahead or astern turbines as desired. The valves are so interlocked that only one can be operated at a time, thus rendering it impossible to admit steam coincidently to the ahead and astern turbines. The interlocking gear is of simple and rigid design and positively fool-proof under all conditions.

The throttle valves are operated by levers working on quadrants and arranged to be held in any position by clamping screws. They are also fitted with handwheels mounted on short external stems independent of the valve stems, which can be screwed-down against the ends of the latter for positive closure of the valves. This feature is also used for regulating the maximum amount of throttle opening under all conditions.

Arrangement of Turbine Steam and Receiver Pipes and Provision for Emergency Operation.—The steam and receiver piping is arranged as shown in Plate I. In order to provide for operating either turbine alone should the other be incapacitated, the pipe joints A, B, C, D, E, F, G, and H are fitted with distance pieces, as indicated. The distance pieces are either blanks or rings, which are inserted for the various conditions of operation as follows:

Condition of Operation	Blank "B," or Ring "R" at (See Plate I)							
	A	B	C	D	E	F	G	H
Both turbines (normal)	B	R	B	R	B	R	R	B
H. P. turbine only (emergency)	B	R	B	R	R	B	B	R
L. P. turbine only (emergency)	R	B	R	B	B	R	R	B

Under either emergency condition, the pinion and flexible coupling of the disabled turbine should be removed from the gear housing.

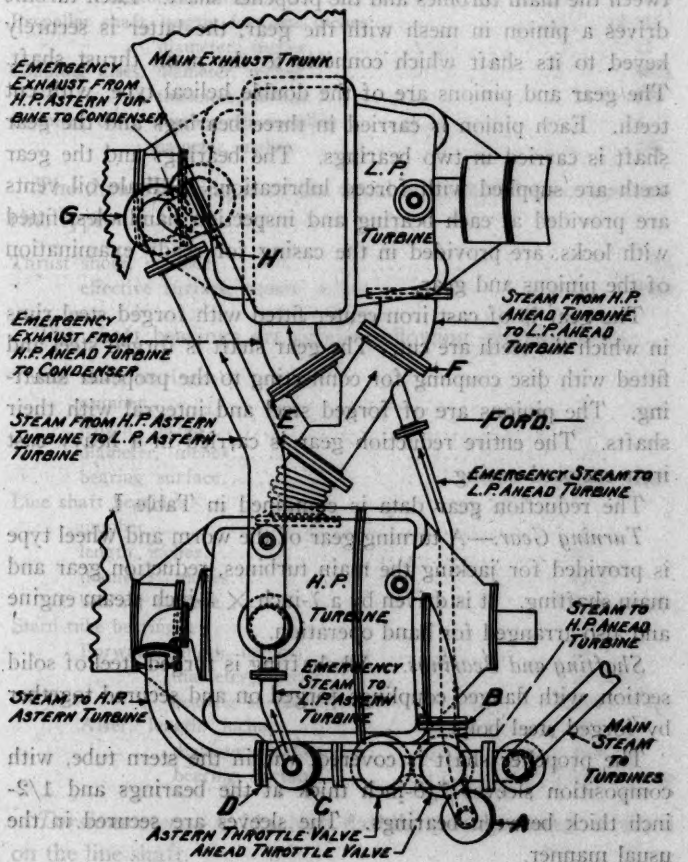

EMERGENCY EXHAUST FROM H.P. ASTERN TURBINE TO CONDENSER
MAIN EXHAUST TRUNK
L.P. TURBINE
G
H
STEAM FROM H.P. AHEAD TURBINE TO L.P. AHEAD TURBINE
EMERGENCY EXHAUST FROM H.P. AHEAD TURBINE TO CONDENSER
F
E
FORD.
STEAM FROM H.P. ASTERN TURBINE TO L.P. ASTERN TURBINE
EMERGENCY STEAM TO L.P. AHEAD TURBINE
H.P. TURBINE
STEAM TO H.P. AHEAD TURBINE
EMERGENCY STEAM TO L.P. ASTERN TURBINE
STEAM TO H.P. ASTERN TURBINE
B
MAIN STEAM TO TURBINES
D
C
A
ASTERN THROTTLE VALVE
AHEAD THROTTLE VALVE

PLATE I.

Reduction Gear.—A one step reduction gear is installed between the main turbines and the propeller shaft. Each turbine drives a pinion in mesh with the gear, the latter is securely keyed to its shaft which connects to the main thrust shaft. The gear and pinions are of the double helical type, with cut teeth. Each pinion is carried in three bearings and the gear shaft is carried in two bearings. The bearings and the gear teeth are supplied with forced lubrication. Telltale oil vents are provided at each bearing and inspection handholes, fitted with locks, are provided in the casing for ready examination of the pinions and gear.

The gear is of cast iron center fitted with forged steel rims in which the teeth are cut. The gear shaft is forged steel and fitted with disc coupling for connecting to the propeller shafting. The pinions are of forged steel and integral with their shafts. The entire reduction gear is carried in a heavy cast iron enclosed casing.

The reduction gear data is contained in Table I.

Turning Gear.—A turning gear of the worm and wheel type is provided for jacking the main turbines, reduction gear and main shafting. It is driven by a 7-inch × 5-inch steam engine and also arranged for hand operation.

Shafting and Bearings.—All shafting is forged steel of solid section, with flanged couplings forged on and secured together by forged steel bolts.

The propeller shaft is covered, within the stern tube, with composition sleeves 7/8-inch thick at the bearings and 1/2-inch thick between bearings. The sleeves are secured in the usual manner.

The shafting is of the following principal dimensions:

Thrust shaft, length, feet and inches	11–6
diameter, inches	14¼
collars, number	10
thickness, inches	2¼
diameter, inches	23½
space between, inches	5
bearing surface, square inches	2742.6

Line shaft, length, feet and inches	21–8⅛
diameter, inches	13½
Propeller shaft, length, feet and inches	17–3¾
diameter, inches	15
Coupling discs, diameter, inches	26¼
thickness, inches	3½
Coupling bolts, number per coupling	8
diameter, inches	2⅞

The thrust bearing is of the usual adjustable horse-shoe marine type.

Thrust shoes, number	10
effective surface, square inches	1920

The shaft bearings are of the following characteristics:

Thrust shaft bearings:	
number	8
length, inches	14¼
diameter, inches	14¼
bearing surface	White metal
Line shaft bearings:	
number	2
length, inches	20
diameter, inches	13½
bearing surface	White metal
Stern tube bearings:	
Forward, length, inches	24
diameter, inches	16 13/16
bearing surface	Lignum vitae
After, length, inches	60
diameter, inches	16¾
bearing surface	Lignum vitae

Torsionmeter.—A MacNab flashlight torsionmeter is fitted on the line shaft.

Propeller.—The propeller is a right-hand true screw. It has four adjustable, detachable blades of manganese bronze. The hub and cap are cast iron. Each blade is secured to the hub by seven 3-inch steel studs and composition nuts. The hub has a taper fit on the propeller shaft, is securely keyed, and held on by a steel nut locked with a key.

PROPELLER DATA.

Diameter, feet and inches	17–6
Pitch as set, feet and inches	14–6
Pitch adjustable from 13 feet 0 inches to 16 feet 0 inches.	
Pitch ratio	0.8285
Projected area, square feet	91.5
Helicoidal area, square feet	102.7
Disc area, square feet	240.5
P.A. ÷ D.A.	0.38
Height of lower tip of blade above keel, inches	13⅛
Immersion of upper tip of blade at load draught, inches	92⅞

Main Condenser.—There is one independent, cylindrical, double-flow, surface condenser located on the port side of the main engine. The shell and heads are of cast iron, tube sheets of rolled Muntz metal 1 3/8 inches thick, and seamless-drawn Admiralty metal tubes No. 16 B.W.G. thick, 3/4-inch outside diameter and 9 feet 3 3/8 inches long. The tubes are packed with corset lacing and brass ferrules. There are 2,366 tubes, giving a total cooling surface of 4,200 square feet.

Vacuum Augmenter.—The main condenser is provided with a vacuum augmenter of the Parsons' type, which takes its suction from the side of the condenser slightly above the bottom, and discharges into a small condenser of 70 square feet of cooling surface.

Main Circulating Pump.—The circulating water is supplied by a double-suction, 14-inch, centrifugal pump, driven by a direct connected reciprocating engine having a cylinder 8 inches in diameter by 10-inch stroke. Two engines are provided, one as standby.

Main Air Pump.—An independent main air pump is installed as noted in Table II.

Auxiliary Condenser.—A small auxiliary condenser of the Wheeler surface type, combined with horizontal air and circulating pump, is located in the engine room outboard of the main condenser. It has 577 tubes, 3/4-inch outside diameter, No. 16 B.W.G. thick and 6 feet 5 1/8 inches long, giving a cooling surface of 705 square feet.

TABLE II.—INDEPENDENT RECIPROCATING PUMPS.

No.	Service.	Size, Type and Make.	Location.
1	Main air	10 in. × 22 in. × 18 in. vertical, twin-beam, single-acting "Worthington."	Engine room
2	Main Feed	12 in. × 8 in. × 24 in. vertical, single, double-acting, "Worthington."	Engine room
1	Auxiliary feed	12 in. × 8 in. × 24 in. vertical, single, double-acting, "Worthington"	Engine room
1	Sanitary	6 in. × 5¼ in. × 6 in., horizontal, duplex, double-acting, "Worthington."	Engine room
1	Combined auxiliary air and circulating	12 in. × 14 in. × 14 in. × 12 in., horizontal, simplex, double-acting, combined, "Worthington."	Engine room
1	Fresh water	4½ in. × 2½ in. × 4 in., horizontal, duplex, double-acting.	Engine room
1	Evaporator feed	4½ in. × 2½ in. × 4 in., horizontal, duplex, double-acting.	Engine room
1	Bilge	6 in. × 5¼ in. × 6 in., horizontal, duplex, double-acting.	Engine room
2	Lubricating oil	6½ in. × 7 in. × 8 in., vertical, simplex, double acting.	Engine room
2	Ballast, fire and bilge	8 in. × 8½ in. × 12 in., horizontal, duplex, double-acting, "Worthington."	1 in engine room 1 in forward pump room
2	Fuel oil service	5¼ in. × 3½ in. × 5 in., horizontal, duplex, double-acting.	Boiler room
2	Fuel oil transfer	10 in. × 6 in. × 10 in., horizontal, duplex, double-acting, "National Transit Pump & Machine Co."	1 in boiler room 1 in forward pump room
2	Cargo oil	18 in. × 14 in. × 24 in., horizontal, duplex, double-acting, "National Transit Pump & Machine Co."	Pump room

Feed Water Heater.—In the engine room, outboard and above the feed pumps, is a No. 12 Reilly, type C. multicoil feed-water heater. Between the feed pumps and the feed heater is a grease extractor. Both the feed heater and the grease extractor can be by-passed.

Hotwell Tank.—One hotwell tank of about 500 gallons total capacity is installed. It is fitted with a float and chronometer valve gear for automatically regulating the feed pumps.

Independent Reciprocating Pumps.—Table II gives the principal data for all independent reciprocating pumps.

Forced Lubrication System.—The main turbine bearings and reduction gear are provided with forced lubrication. The system includes two oil pumps, two oil coolers, one oil drain tank of 370 gallons capacity, one 450 gallon gravity oil tank, one 450 gallon oil settling tank, three oil storage tanks of 1,050 gallons combined capacity, and the necessary strainers, thermometers, etc.

The pumps draw from the oil drain tank and discharge through, or by-pass, the coolers to the gravity tank, which is located at high elevation in the engine room hatch supplying oil by gravity to the turbine bearings and reduction gears, the discharge from which is led back to the drain tank. The pumps are also arranged to discharge to the turbine bearings and reduction gear direct; also to the settling tank, which with the storage tanks have gravity connections to the drain tank for replenishing the system.

The pumps' suction and discharge are provided with duplex strainers, also an individual strainer is fitted in the discharge to each bearing and reduction gear spray nozzles. The drains from all bearings are fitted with thermometers. A thermometer is also fitted on the inlet to and outlet from the oil coolers.

The gravity tank is fitted with an automatic alarm to indicate low oil level.

The settling tank is fitted with steam heating coils for separating water from the oil, the water being drained off to the bilge.

Cooling water for the oil coolers is supplied by the main circulating pump, with an emergency connection from the sanitary system.

A rotary hand pump, discharging to the bilge, is provided for clearing the drain tank of water and sediment.

The storage tanks are filled through a suitable deck connection.

Boilers.—There are three main, horizontal, single-ended, Scotch boilers and one horizontal, single-ended, Scotch donkey boiler, all fitted with separate combustion chambers, and arranged to burn fuel oil. The main boilers are placed abreast just forward of the main turbines, with fire room forward. The donkey boiler is located in the boiler hatch at the upper deck level.

BOILER DATA.

	Main (each).	Donkey.
Working pressure, pounds	220	180
Test pressure, pounds	330	270
Diameter, external, feet and inches	14–7 3/16	11–1
Length, over heads, feet and inches	11–6	10–10½
Furnaces, number	3	2
type	Morrison, Suspension	
diameter, internal, inches	43	39
length, external, feet and inches	8–1 13/16	7–9⅛
Heating surface, square feet	2345	1223
Tubes, material	Charcoal iron, lap welded	
number, ordinary	250	132
stay	100	56
outside diameter, inches	2¾	2¾
thickness, ordinary, B.W.G.	No. 10	No. 10.
stay, inches	5/16	5/16
length, ordinary, inches	93½	89
stay, inches	94¼	89¾
Safety valve, type	Twin, Ashton	
size	3	2½

Uptakes.—Uptakes of usual design for Howden, heated air, forced draft, connect the main boiler tube nests to the smoke

pipe. For heating the air, 789 3-inch by No. 12 B.W.G. tubes, presenting a total heating surface of 2,169 square feet, are installed vertically in the uptakes. The gases of combustion pass through the tubes and the forced draft air outside.

The donkey boiler uptake connects into the smoke pipe immediately below the top of the boiler hatch.

Dampers are fitted in all uptakes.

Smoke Pipe.—There is one double casing smoke pipe, 8 feet 1 inch outside diameter and 80 feet high above the center of the lower furnaces. The clear cross-section area through the smoke pipe is 41.29 square feet.

The donkey boiler smoke pipe is inside the main smoke pipe and extends to the top. It is of single casing construction 33 inches inside diameter.

Forced Draft.—Howden, closed ash pit, heated air, forced draft is used for the main boilers. The air is supplied by one vertical, engine-driven, Sturtevant Type VS7, double-inlet, blower, with 110-inch diameter fan. The fan is provided with duplicate single engines, one being a standby. Each engine has a cylinder 7 inches diameter by 6 inches stroke, and is capable of driving the fan at 390 revolutions per minute. The unit is located in the engine room, starboard side, forward. The air is drawn from the engine room and delivered, through sheet-iron ducts of rectangular section, to the heater boxes in the uptakes, thence to the ash pits.

Fire Room Hoist.—A hoist of the steam ram type is fitted in the starboard ventilator to the fire room.

Fuel Oil System.—The Dahl system of mechanical oil-fuel burning is installed for both the main and donkey boilers. The apparatus comprises one oil burner per furnace, three oil heaters, two oil-fuel service and two oil-fuel transfer pumps, together with the necessary strainers, piping, etc. The service pumps are arranged to draw from all bunker tanks, including summer tanks No. 5 and cofferdam No. 3, which are fitted for carrying bunker oil-fuel, and they discharge to the

burners through the oil-fuel heaters or bypass same. All bunker tanks are fitted with high and low suctions.

Steam Piping.—The main steam pipe is of seamless drawn steel. The feeders from the boilers are 6 inches each, uniting into an 7-inch pipe leading to the main H.P. turbine twin throttle valve. A 4 1/2-inch auxiliary steam connection is taken off each main boiler, forming a main with branches to the engine room and deck, from which sub-branches are taken as required. The donkey boiler has a 4-inch connection to the auxiliary steam line. A 2 1/2-inch independent steam line is led from the donkey boiler and No. 1 main boiler to the generator sets in the engine room; they also take steam from the auxiliary steam line in the engine room.

Auxiliary Exhaust Piping.—The exhaust steam from all auxiliaries is collected in a common main connecting to the main and auxiliary condensers, and the feed water heater. A back pressure valve is fitted at each condenser connection to maintain the necessary pressure on the line for the feed water heater. There is also a connection from the auxiliary exhaust line to the 1st stage of the L.P. turbine. Care must be taken, however, when stopping or going astern, that the auxiliary exhaust is immediately shut off from the turbine; otherwise the rotor may be distorted due to unequal heating and the blading damaged.

Feed System.—Three feed pumps are provided as listed in Table II. All feed pumps take their suction from the hotwell tank and are arranged to feed the boilers direct or through the feed water heater. The feed stop and check valves are at the rear end of the boilers and are controlled from the engine room. One No. 13 1/2 and one No. 10 1/2 Metropolitan injector are also connected to the feed lines.

Evaporating and Distilling Plant.—The plant consists of two Reilly multicoil evaporators, each having a capacity of 35 tons of fresh water per 24 hours, and two Reilly multicoil, vertical distillers, each of 6,000 gallons capacity per 24 hours,

together with the necessary pumps as listed in Table II. The evaporators are located in the engine room, at the working level, starboard side, aft, with the distillers above at high elevation in the engine hatch.

Refrigerating Plant.—The ice machine room is to starboard of the engine room, and it is entered from the middle grating. The outfit includes a 2-ton Kroeschell, vertical, double acting, CO_2 compressor driven by a direct-connected steam engine, oil separator, CO_2 receiver and condenser, together with the usual appurtenances.

The refrigerating rooms are on the main deck abaft the engine room.

Lighting Plant.—There are two G. E. Co. direct current, 20-KW, horizontal, compound-wound, Type MP6-20-400, generators, each driven by a 9-inch × 7-inch vertical, single, direct-connected, steam engine. They are located on a flat in the after end of the engine room. The switchboard is just abaft the generators. Current is supplied at 110 volts.

An emergency generator-set is also provided. It is located on the upper deck forward and consists of a Westinghouse, direct current, 12.5 kilowatt, 125 volt, generator, designed for 600 revolutions per minute, and driven by a 25 horsepower, four-cylinder, Clifton Motor Works kerosene engine.

Workshop.—A small workshop is provided to starboard of the engine room, at the level of the middle grating. It is equipped with the following tools and equipment:

1 16-inch Steptoe shaper.
1 Buffalo Forge Co. hand drill.
1 12-inch Blount, double-energy grinder.
1 Grindstone.
1 16-inch Davis lathe.
1 20-inch Fairbanks upright drill.
1 Anvil.
1 Portable forge.

1 Work bench.
2 Vises.
Outfit of hand tools.

All tools are belt driven from overhead shaft and pulleys. The power is supplied by a 7 H.P., G. E. Co., direct-current motor, designed for 1,150 revolutions per minute.

TRIALS.

The contract required:

(*a*) A trial over a measured mile in the deepest water available and at the highest speed obtainable, not less than three runs over the mile to be made, and the mean speed and revolutions for these runs carefully ascertained.

(*b*) A full speed trial of four hours' duration in deep water at the highest speed attainable (not less than 10 1/2 knots), to be determined by the average revolutions of the main shaft according to the measured mile trial. During this trial all the auxiliaries necessary for the service of the vessel, including dynamos for efficient lighting, shall be in operation. The fuel oil consumption on this trial to be measured and not to exceed the equivalent of 325 pounds per knot at 10 1/2 knots.

(*c*) Turning and backing trials to test the engines and steering gear.

The above requirements, however, were much enlarged upon by the contractors, as shown in the following description of the trials.

On the morning of August 31, 1920, the *Trinity* sailed from Newport News, Va., for the measured mile course off the Delaware Breakwater. A brief stop was made off Old Point Comfort to pick up the Trial Board, during which time the shaft was dragged to ascertain the zero reading of the torsion meter. Off Cape Henry the vessel was swung for the purpose of adjusting the compasses, upon completion of which she proceeded on her course up the coast.

Four-Hour Official Full-Power Trial.—This trial was conducted on the run up the coast. It was extended to four and one-half hours duration and divided into two periods as follows: During the first two and one-half hours the water consumption of the main turbines and auxiliaries was measured, using the excess auxiliary exhaust in the L.P. turbine, and during the last two hours that of the main turbines only was measured, with no auxiliary exhaust admitted to the L.P. turbine; other conditions remaining unchanged. The fuel oil consumption was measured continuously throughout the four and one-half hours of the trial. The data obtained on this trial are given in Table III.

Steering and Backing Tests.—Upon conclusion of the full power trial the astern steering and reversing tests were conducted, the ahead steering test, including the figure eight, having been run at the end of the compass adjustment.

The results of the ahead steering tests were as follows:

Rudder from center to full right..... 20.5 sec.
Steam pressure drop from 160 pounds to 125 pounds.
Rudder from full right to full left..... 30 sec.
Steam pressure drop from 160 pounds to 120 pounds.
Rudder from full left to center..... 11.5 sec.
Steam pressure drop from 160 pounds to 120 pounds.

The results of the astern steering tests were as follows:

Rudder from center to 35 degrees left..... 12 sec.
Steam pressure drop from 155 pounds to 120 pounds.
Rudder from 35 degrees left to 35 degrees right..... 22 sec.
Steam pressure drop from 155 pounds to 118 pounds.
Rudder from 35 degrees right to center..... 12 sec.
Steam pressure drop from 155 pounds to 120 pounds.

The results of the reversing tests were as follows:

Time for turbines to stop from full ahead..... 55 sec.
Time for turbines to reach full astern from full ahead... 3 min. 50 sec.
Time for ship to become dead in water..... 7 min. 30 sec.
Headway reached..... 1,235 yards.
Time for turbines to stop from full astern..... 30 sec.
Time for turbines to reach full ahead from full astern.... 2 min. 10 sec.

The reversing tests were repeated on September 1, 1920, after the standardization trials, with the following results:

Time for turbines to stop from full ahead.....	33 sec.
Time for turbines to reach full astern from full ahead....	2 min. 32 sec.
Time for ship to become dead in water.....	5 min. 58 sec.
Headway reached	1,119 yards.
Time for turbines to stop from full astern.....	20 sec.

The pressures, R.P.M. and S.H.P. during the astern runs were as follows:

Time	H. P. Astern Chest	L. P. Astern Chest	Cond. Vac.	L. P. Exh. Temp.	R.P.M.	S. H. P.
August 31, 1920			Inches			
4:44	150	0	29	97	57	1,105
4:46	145	0	28.8	...	58	1,162
4:48	145	0	29	97	57	1,160
4:50	150	..	.....	...	57	1,160
4:52	150	0	28 8	...	60	1,300
4:54	.....	..	.....	...	60	1,300
September 1, 1920						
12:02	.....	..	.....	...	68	1,560
12:04	175	..	.....	...	62	1,550
12:06	.....	..	.....	...	62	1,420

The maximum astern chest pressure at which the boiler pressure could be kept up was 175 pounds.

Two-Hour Full Power Trial with no Auxiliary Exhaust Admitted to the L.P. Turbine.—Following the astern steering and reversing tests a special two-hour trial at full power was conducted to ascertain the oil consumption and the water consumption of the turbines and auxiliaries with no auxiliary exhaust admitted to the L.P. turbine. This run was conducted under similar conditions to the last two hours of the four and one-half hour full power trial, hence, the difference in water rates between the two is the actual water rate of the auxiliaries; likewise the difference in water rates between this run and the

first two and one-half hours of the four and one-half hour full power trial is the amount by which the total water rate is reduced by using the excess auxiliary exhaust in the L.P. turbine. The data collected are given in Table III.

About midnight the *Trinity* dropped anchor off the Delaware Breakwater.

Standardization Trial.—About 6:30 A.M., September 1, 1920, the *Trinity* started to weigh anchor, but owing to a blow-out of the windlass engine piston rod packings the start for the measured mile was delayed until about two hours later. The displacement was estimated to be 16,590 tons. Nine runs were made over the course during which the following figures were obtained:

			S. H. P.* (Forward T. M. Scale Readings)
Group No. 1:	Run No. 1 S– 8.007 knots	70.07 R. P. M.	1,425
	Run No. 2 N– 9.934 knots	69.37 R. P. M.	1,453
	Run No. 3 S– 8.280 knots	71.48 R. P. M.	1,518
	Average – 9.039 knots	70.07 R. P. M.	1,450
Group No. 2:	Run No. 4 N–11.033 knots	80.17 R. P. M.	2,420
	Run No. 5 S–10.110 knots	82.39 R. P. M.	2,418
	Run No. 6 N–10.746 knots	79.88 R. P. M.	2,305
	Average –10.50 knots	81.21 R. P. M.	2,387
Group No. 3:	Run No. 7 S–11.662 knots	91.54 R. P. M.	3,320
	Run No. 8 N–11.542 knots	92.05 R. P. M.	3,550
	Run No. 9 S–12.510 knots	93.22 R. P. M.	3,600
	Average –11.815 knots	92.22 R. P. M.	3,505

The curves, Plate II, were plotted from the above data.

* As the after scale reading of the torsion meter was from 8 to 10 units higher than the forward scale reading, the S.H.P. throughout is based on the forward reading, which was used in the shop calibration of the shaft, rather than the average reading of the forward and after scales.

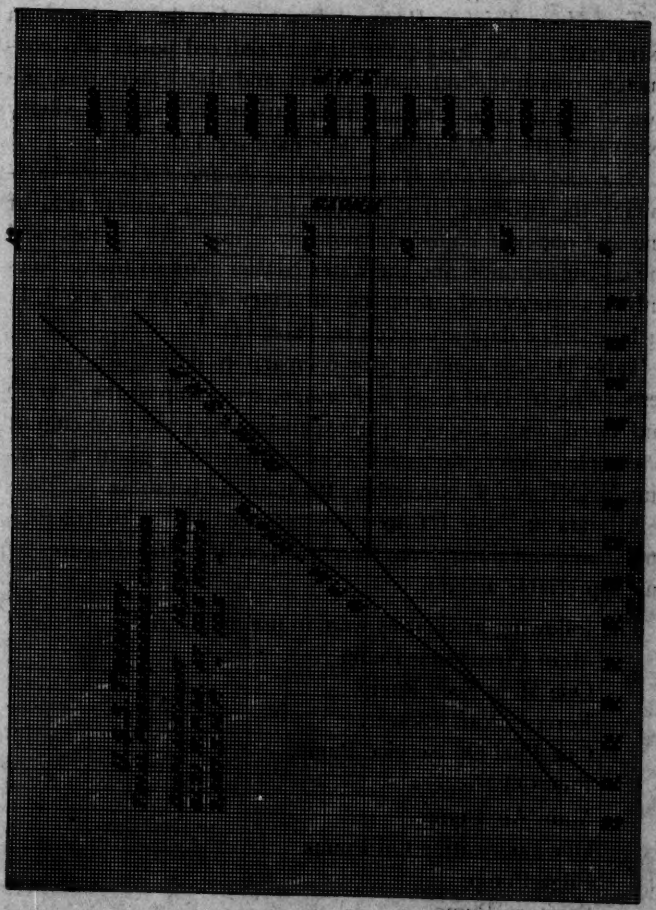


PLATE II.

The standardization trial was completed at noon, following which the Trial Board was put ashore and the vessel proceeded to sea for the Virginia Capes.

Two-Hour Trial at Reduced Power.—On the run home an extra trial of two hours' duration at reduced power was conducted, measuring oil consumption and the water consumption of the turbines and auxiliaries, using the excess auxiliary exhaust in the L.P. turbine. For data see Table III.

One and One-Half Hour Trial at Reduced Power.—Following the two-hour trial at reduced power a similar trial of one and one-half hours' duration was run. During this trial the oil consumption and the water consumption of the turbines only was measured, using no auxiliary exhaust in the L.P. turbine. The data are given in Table III.

Table III also contains, for comparison, data taken on corresponding trials of U. S. S. *Ramapo*, sister ship of the *Trinity* and fitted with a quadruple expansion reciprocating engine. A complete description of U. S. S. *Ramapo* is given in Volume XXXI, No. 4, November, 1919, of the JOURNAL.

All data in Table III are those recorded by the contractors, and should not differ from the corresponding official figures by any appreciable amount.

The following auxiliaries were in use on all trials:

Main Circulating Pump.
One Main Feed Pump.
Forced Draft Blower.
One Fuel Oil Service Pump.
Fuel Oil Heaters.
Main Air Pump.
One Lubricating Oil Pump.
Bilge Pump.
Sanitary Pump.
Fuel Oil Transfer Pump } (Pumping oil and water to
Auxiliary Feed Pump } measuring tanks.)

Stages	No. of Expansion Nozzles	No. of Rows.		Approximate No. per Row	
		Casing	Rotor	Casing	Roto
					54"
1st	11	1	2	73	400
2nd	60		1		377
3rd	60		1		400
4th	62		1		399
5th	64		1		398
6th	64		1		396
					50-1/2"
1st	8	1	1	62	306
		1	1	62	302
			1		300
					L.
1st		1	1	298	300
2nd		1	1	300	300
3rd		1	1	308	300
4th		1	1	312	300
5th		1	1	316	300
6th		1	1	320	300
7th		1	1	328	300
8th		1	1	334	300
9th		1	1	342	300
10th		1	1	350	300
11th		1	1	356	300
12th		1	1	302	246
13th		1	1	318	246
14th		1	1	318	246
					51" L
1st	24	1	1	348	306
		1	1	358	302
			1		300

Reduction Gear Data.

	Gear Wheel	Pi
Number of teeth	533	
Diam. of pitch circle	113.164"	7
" over teeth	113.535"	7
Circular pitch	0.667"	0
Helical angle	29°-4'-1.7"	29°-
Diam. shaft journals	14"	
R. P. M.	90	1
Gear ratio	1:16.15	

Table I.

Turbine Data.

Blades

Approximate No. per Row.		Length, inches.		Circumferential Pitch at base, inches		Tip Clearance, inches.	
Casing	Rotor	Casing	Rotor	Casing	Rotor	Casing	Rotor
			54" H.P. Ahead Turbine.				
73	400	2.595	2.095	0.45	0.41		
	377		2.720		0.41		
	400		1.7825		0.41		
	400		1.845		0.41		
	399		1.970		0.41		
	398		2.220		0.41		
	396		2.5825		0.41		
			50-1/2" H.P. Astern Turbine.				
	306		2.36125		0.50		
62	302	2.88125	3.0375	0.50	0.50		
62	300	3.56875	3.6625	0.50	0.50		
			L.P. Ahead Turbine.				
298	300	2.470	2.470	0.46	0.41	.04	.06
300	300	2.658	2.658	0.46	0.41	.04	.06
308	300	3.220	3.220	0.46	0.41	.04	.06
312	300	3.533	3.533	0.46	0.41	.04	.06
316	300	3.845	3.845	0.46	0.41	.04	.06
320	300	4.158	4.158	0.46	0.41	.04	.06
328	300	4.658	4.658	0.46	0.41	.04	.06
334	300	5.095	5.095	0.46	0.41	.06	.08
342	300	5.720	5.720	0.46	0.41	.06	.08
350	300	6.345	6.345	0.46	0.41	.06	.08
356	300	6.845	6.845	0.46	0.41	.06	.08
302	246	7.725	7.725	0.56	0.50	.07	.09
318	246	9.100	9.100	0.56	0.50	.07	.09
318	246	9.100	9.100	0.56	0.50	.07	.09
			51" L. P. Astern Turbine.				
	306		3.063		0.50		
348	302	3.975	4.131	0.50	0.50		
358	300	5.969	5.1625	0.50	0.50		

Data.		Turbine Roter Shafting and Drums.		
ar el	Pinions		H.P.Turbine	L.P.Turbine
33	33	Drum, ahead turbine, diameter	None	39 1/8"
164"	7.006"	length	None	2'-6 1/8"
535"	7.377"	Shaft, length	10 -8 17/32"	10'-9 25/32"
567"	0.567"	diameter, maximum	11½"	11½"
-1.7"	29°-4'-1.7"	at journals	7"	7"
14"	6"			
00	1455.6			
	1:16.15			

TABLE

	U.S.		
	Full Power Trials.		
	4½ Hours Official	2½ Hours Measuring Oil & Water Main Turbines & Aux.	2 Hours Measuring Oil & Water Main Turbines only.
Date of trial	Aug.31,1920	Aug.31,1920	Aug.31,1920
Time	12 M. to 4:30 P.M.	12 M. to 2:30 P.M.	2:30 P.M. to 4:30 P.M.
Speed in knots (from curve)	11.24	11.25	11.21
Slip of propeller, per cent.	10.01	10.04	10.06
Displacement, tons	16,617	16,617	16,617
Pressures (average):			
Main steam, boilers, lbs. gauge	215	215	215
" engine room, lbs. gauge	213	213	214
" H.P. chest, " "	211	211	211
" H.P. 1st stage, lbs. gauge	60	60	60
" L.P. chest, " "	1.4	2.1	1.0
Vacuum, main cond., inches of mercury	27.8	27.8	27.8
Barometer, inches of mercury	30.049	30.049	30.049
Main feed, lbs. gauge	251	252	249
Gland steam, lbs. gauge	0.5	0.5	0.5
Augmenter steam, lbs. gauge	194	194	193
Auxiliary exhaust, lbs. gauge	10	10	9
Fuel oil to burners, lbs. gauge	131	134	124
Forced draft, inches of water	1.5	1.8	1.5
R.P.M. or double strokes per min. (average):			
Propeller	97.88	97.4	97.1
Main circulating pump	185	185	185
" air pump	28	30	28
" feed pump	15	15	15
Forced draft blower	288	297	264
Fuel oil service pumps	13	15	14
S.H.P. (average)	2,980	2,980	2,980
Temperatures, degrees F. (average):			
Main injection	75	74	77
" overboard discharge	93	93	95
" air pump "	---	---	---
" exhaust	99	99	98
Hotwell	116	124	106
Main feed	204	210	198
Air to forced draft blower	100	101	99
Fuel oil to burners	185	185	181
Smoke pipe	522	526	518
Lubricating oil to cooler	---	105	104.2
" " from "	---	95	98.9
Engine room working level	---	110.4	111
Fire room " "	---	---	---
Outside air	---	82.2	81.4
Water consumption: [*]			
Pounds per hour, main turbines	---	---	38,600
" " and aux.	---	47,504	---
per S.H.P.	---	16	15.54
evaporated, actual	---	48,010	---
per sq.ft. of H.S.	---	0.85	---
per lb. of oil, actual	---	14.05	---
from and at 212° F.	---	14.8	---
Total make-up feed, gallons	---	512	778
Fuel oil consumption: [**]			
(Oil analysis: 18614 B.t.u. per lb., Specific gravity at 60° F. 0.9156, Baume degrees at 60° F. 23.7°, Flash point 176° F.)		Actual | Based on 19000 B.t.u.	Actual | Based on 19000 B.t.u.
Pounds per hour	---	3,480 | 3,380	3,386 | 3,218
knot run	---	308 | 296	299 | 286
at 10.5 knots,	---	288 | 287	--- | ---
guaranteed	---	325	---
below guarantee	---	45 | 38	--- | ---
hour per S.H.P.	---	1.174 | 1.160	1.134 | 1.140
sq. ft. of H.S.	---	0.487 | 0.477	0.481 | 0.471
Miscellaneous data:			
Per cent. CO2	10.5	10.3	10.6
Number of boilers in use	3	3	3
" " burners " "	9	9	9
Auxiliary exhaust admitted to	---	L.P. turbine & feed heater	Feed heater & aux. cond.
Number of nozzles open	9	9	9

[*] Based on 2½ hour period. [**] 2,770 lbs. per hr., based on 2½ hour period, used for evaporation comput
‡ Indicated Horse Power. ‡‡ Reciprocating engines. x Per I.H.P. main engine. xx One boiler cut out d

TABLE XII.

U.S.S. TRINITY.				U.S.S. RAMAPO.			
Power Trials.		Reduced Power Trials.		Full Power Trials.		Reduced Power Trials.	
2 Hours Measuring Oil & Water Main Turbines only.	2 Hours Measuring Oil & Water Main Turbines & Aux.	2 Hours Measuring Oil & Water Main Turbines & Aux.	1½ Hours Measuring Oil & Water Main Turbines only.	3 Hours Measuring Oil & Water M.T. & Aux.	2 Hours Measuring Oil & Water M.T. only.	4 Hours Measuring Oil & Water M.T. & Aux.	2 Hours Measuring Oil & Water M.T. only.
Aug.31,1920 2:30 P.M. to 4:30 P.M.	Aug.31,1920 5:30 P.M. to 7:30 P.M.	Sept.1,1920 3:45 P.M. to 5:45 P.M.	Sept.1,1920 6:00 P.M. to 7:30 P.M.	Oct.15,1919 11:45 A.M. to 2:45 P.M.	Oct.15,1919 3:15 P.M. to 5:15 P.M.	Oct.16,1919 3:15 P.M. to 6:15 P.M.	Oct.16,1919 6:30 P.M. to 8:30 P.M.
11.21	11.15	10.45	10.14	11.19	11.22	9.09	9.16
10.06	9.97	9.61	9.62	13.1	13.22	13.57	13.58
16,617	16,617	16,890	16,890	16,648	16,648	16,622	16,622
216	215	212	204	222	222	220	220
214	210	211	205	---	---	---	---
211	206	209	201	218	217	216	215
60	59	42	40	---	---	---	---
1.0	0	0.65	1 inch	---	-----	---	---
27.8	27.9	28	28.5	27.8	27.9	28	28
30.049	30.049	30.065	30.065	30.48	30.48	30.35	30.35
249	244	241	241	244	248	247	248
0.5	0.5	1	0.6	---	---	---	---
195	192	196	149	---	---	---	---
8	7	7	7	12	11.6	10	9
124	117	155	167	164	152	98	106
1.5	1.5	1.66	1.9	1.24	1.26	0.6	0.4
87.1	86.84	80.6	78.4	74.2	74.2	89	89.8
155	150	147	147	109.7	114.5	118	110
28	26	21	20		(Attached air pump.)		
19	12	10	11	12.2	11.6	6	7
264	270	289	301	289	276	154	148
14	15	---	11	11.6	14	8	9
2,850	2,810	2,295	2,166	2,950 #	2,950 #	1,650 #	1,646 #
77	76	72	72	70.3	67.3	68	68
95	95	92	91	101.3	94	80	79
---	108	102	99	114.4	97.7	87	86
98	98	100	99	---	---	---	---
106	113	112	98	102.2	101.3	97	94
199	194	206	204	196	176	188	192
99	100	97	97	104	102.5	90	90
161	155	152	155	144.5	139.5	139	148
515	506	480	515	548	548	424	480
104.2	---	---	---	---	---	---	---
98.9	---	---	---	---	---	---	---
111	---	---	---	98.4	98.5	86	86
---	---	---	---	110	109	84	86
81.4	---	---	---	---	---	---	---
28,600	---	---	29,900	---	38,251 ##	---	20,196 ##
---	45,900	37,845	---	42,161 ##	---	23,134 ##	---
13.84	16.3	16.49	15.81	14.4 x	12.8 x	14.18x	12 x
---	45,178	38,840 *	---	45,701	---	24,673	---
---	6.55	****	---	6.28	---	xx	---
---	13.84	14.01	---	13.8	---	15.8	---
---	14.8	14.61	---	14.4	---	14.88	---
778	840	646	255	---	---	---	---

(Oil analysis: 19099 B.T.U. per lb., Specific gravity at 60° F. 0.92, Baume degrees at 60° F. 22, Flash point 280° F.)

Actual	Based on 19000 B.T.U.	Actual	Based on 19000 B.T.U.	Actual	Based on 19000 B.T.U.	Actual	Based on 19000 B.T.U.				
2,286	2,218	2,285	2,248	2,725**	2,670	2,729	2,644	2,246	2,220	1,227	1,241
289	285	300	294	289	284	264	259	289	297	198	198
---	---	---	---	---	---	---	---	275	---	---	---
	---		---		---		---	325	---	---	---
--	--	--	--	--	--	--	--	82	---	---	---
1.184	1.160	1.179	1.158	1.179	1.155	1.237	1.212	1.1x	1.112x	1.107x	1.079x
0.461	0.472	0.475	0.464	****	****'	0.230	0.246	0.462	0.477	xx	0.286
10.6		12.8		11.8		11.8		10	9.36	10.6	9.7
5		5		3 for ½ hr. 2 " 1½ hrs.		2		5	5	3 for 1½ hrs. 2 " ½ "	5
9		9		6		6		9	9	4 to 6	4 to 6
Feed heater & aux. cond.		Feed heater & main cond.		L.P.turbine & feed heater		Feed heater & aux.cond.		---	---	---	---
9		9		7		7		---	---	---	---

eration computations. *** All water and oil consumptions corrected for the extra pumps used for measuring water & oil.
iler cut out during run. **** Yarrow's boiler cut out at 4:30 P.M.

Auxiliary Air and Circulating Pump (On Runs Nos. 3 and 8).
Steering Engine.
Galley.
One Dynamo.
Ice Machine.

Heating system, evaporators and heater coils in fuel oil tank were not in use.

Acknowledgment is here made of my indebtedness to the contractors, who courteously furnished all trial data used in the preparation of this article and otherwise rendered valuable assistance.

NOTES.

THE DESIGN OF WAR VESSELS AS AFFECTED BY THE WORLD WAR.*

By Rear Admiral David Watson Taylor.

Chief Constructor U.S.N., Chief of Bureau of Construction and Repair, Navy Department, Washington, D. C.
Member of the Institute.

The Battle of Trafalgar was fought October 21, 1805, or early in the nineteenth century. In the early part of the present century the tactics employed in that battle were still being discussed, but although Nelson's Flagship, the *Victory*, is preserved by England at Portsmouth, it is of no interest from a material point of view to designers of war vessels of the present day. Similarly, with the rapid engineering development of naval material which has been going on for more than fifty years and bids fair to continue, the material lessons from the World War must be gathered within a comparatively short time. Even so, to answer fully the question, "What has been the effect of the World War on warship design?" is not as yet possible. For years it will be necessary to collate and study an enormous mass of experience, some written, some oral, some originating from the responsible controlling bodies of the great navies, and much from individuals, including not only those of great eminence, but many whose names will never emerge from comparative obscurity, though their experience in the aggregate may in the long run exercise a dominating influence.

As a practical proposition the full effect of war experience will be demonstrated in concrete form only after service opinion has been crystallized and become definite in direction as a result of study and discussion by a large number of officers. Certainly that will be the case in the American Navy where the organization is such that service opinion necessarily controls policy in the development of naval types. The service is a customer of the naval designer, and although the latter may influence and at times interpret and lead service opinion, the customer will have what he demands. What I say today must therefore be taken more in the light of a discussion of this intensely interesting subject, than as a hard-and-fast laying down of principles or expressions of final opinion.

Let me call attention at once to the fact that, after all, there has been nothing startling or revolutionary brought about by the experience of fifty-one months of war. There has mainly resulted an intensive development of each of the accepted types which existed at the outbreak of the war and which were the results of many years of study, experiment, and practice in all of the great navies of the world. It is true that some new types have appeared, but with one exception, namely, aircraft carriers, they have been of minor importance when measured by the cost and time required for production.

* Presented at the Stated Meeting of the Institute held Wednesday, April 21, 1920.

When we consider types and not details, we must not look only to the few naval battles of the World War which can justly be classed as major actions for the influences affecting our naval construction of the future. It is necessary to consider the particular trend of naval events, the accumulated experience, and the principal phases of naval activity during the more than four years of hostilities.

The first of these must naturally be the causes which gave not only the initial but the continuing command of the sea to the Allies. We know that at the outbreak of the war all German mercantile vessels quickly disappeared from the high seas, being either held in their own ports or promptly interned in neutral ports. On the other hand, Allied commerce proceeded on its way. It was not the great British Battle Fleet which the German merchantmen feared, for they knew that this Fleet would be concentrated at one point within easy striking distance of the German coasts and therefore it could be easily avoided. What they feared were the Allied Cruisers, Auxiliaries, Destroyers and light vessels of every class. Just as the few German Cruisers which were at large were captured or sunk within a few months, so could this cloud of Allied light craft have been swept from the seas had the German heavy fighting forces been able to operate without first giving battle to the superior British Battle Fleet. They were unable to do this at any time during the war. As a result every military effort of the Central Powers afloat and ashore was made more difficult because of the slow but sure throttling of their economic and industrial life. Without the British Battle Fleet the blockade of Germany would have been ineffective. This factor had such a determining influence, both on the duration and final outcome of the war, that the types of vessel which make up the main fighting fleets are more firmly established than ever as the essential ones contributing to naval power. If these great battleships and battle cruisers disappear, either in the near or the distant future, it will be as a result of engineering progress and the invention and perfection of new weapons and not as a result of the World War.

Battleships and battle cruisers were in actual conflict with vessels of the same type and power on only two occasions: at the Dogger Bank on January 24, 1915, and at Jutland on May 31, 1916. These actions, however, do not by any means represent the sum total of their activity. When the location and activity of the German Cruiser Squadron in the Pacific was disclosed by the tragedy off Coronel, two battle cruisers at once sailed to search out and destroy this troublesome squadron. Perhaps they were lucky in coming into contact with the enemy immediately, but the celerity and success with which they accomplished their mission at the Falkland Islands gave a great impetus to the favor in which this type was held by naval men. The immediate effect of this sentiment was seen in the British battle cruisers *Repulse* and *Renown*, which represent the extreme of the type; that is, armor and gunpower were sacrificed to speed to an even greater extent than in the original battle cruiser. These were quickly followed by an even greater extreme, the *Courageous*, *Furious* and *Glorious*, which can be denominated either small light battle cruisers or enormously large light cruisers, as they have the largest guns characteristic of the former and the total absence of armor protection characteristic of the latter, while possessing the high speed common to both. The battle off Dogger Bank served only to confirm the conclusions on which these two classes of ships had been laid down. In this engagement, the rival battle cruisers met for the first time, with the result that those on both sides demonstrated their ability to stand heavy punishment without succumbing to

fatal damage. Even the older German cruiser *Blucher*, which was inferior in gunpower, protection and speed to all of the others, succumbed only after surviving for a considerable period of extremely heavy punishment. If there had been no further war experience with the battle cruiser type it is likely that the idea that protection is not important for them would have prevailed, and the combination of extreme speed, guns of the largest size, and the minimum of protection might have been in favor for some years. But the Battle of Jutland gave a rude shock to opinions based on earlier actions.

The Battle of Jutland is easily the foremost single event of modern naval history. The controversial phases of the tactics employed in this battle are only of interest to the naval designer in so far as the material in the two fleets influenced the judgment and decisions of the high command on each side, and to the extent that new instruments of naval warfare, not then available but developed since, would have exercised a determining influence in the tactics employed; in the latter class comes the use of aircraft, and I will have occasion later in this paper to refer to the use and influence of aircraft in naval operations from the designer's point of view. By far the most important aspect of this engagement to the designer is the manner in which the various types of vessels engaged fulfilled the functions for which they were originally designed. In regard to type, the first outstanding fact is that battle cruisers must inevitably play an important rôle in major fleet actions. Each side in turn, first the Germans and then the British, used their battle cruisers to lead the whole or a portion of the enemy's fleet to contact with the main body of their own fleet. In fact, with the single exception of the *Warspite*, it was the battle cruisers on both sides that stood the brunt of the action and received the lion's share of punishment from the enemy. If the battle had been fought to a finish between the battleships, there might have been a different story to tell. The losses and heavy damages sustaind by the vessels of battle cruiser type bear out to some extent the pre-war contentions of those who maintained that it was not fit to take its place in the line of battle. On the other hand, excepting their greater vulnerability, it cannot be denied that they acquitted themselves with credit even when pitted against the more heavily armed and armored battleship. Furthermore, not only was the value of their great speed demonstrated, but also the value of one side holding the speed gauge over the other was shown, for, it was due to the possession of higher speed by the British that the German Fleet, at the end of the second phase of the battle, found itself in a position which was so bad tactically that the German Chief-of-Staff is quoted as saying that if any Admiral had involved himself in such a position in peace time maneuvers he would never again have obtained a command afloat. Another result from this action of general influence on type is found in connection with the use of older battleships, generally referred to as of the "Pre-dreadnaught" era. The German Fleet included one squadron of vessels of this type, and this squadron not only failed to be of any essential assistance to them but proved actually to be a handicap on their freedom of maneuver. The force of this lesson was shown by the fact that subsequent to the battle most of the German battleships of this type were retired from active commission. The material weakness of this type of older ships, when opposed to the most modern weapons, was shown in the case of the *Pommern*, which blew up and sunk immediately as a result of a single torpedo. The ineffectiveness of these older ships, as shown by many incidents of war, will be referred to later.

The ability of the large, modern, heavily-armored ships not only to survive, but to continue in action after the most severe punishment, was perhaps best shown by the British battleship *Warspite*, which, due to an unfortunate accident to the steering gear, sheered out of the battle line and made two complete circles within short range of the German Fleet. This vessel was hit by major caliber shell between 20 and 25 times. The net result of this tremendous hammering was that one out of eight 15-inch guns was put out of action; there was no damage of any kind to her main machinery plant; the upper works and unprotected portions of the ship were riddled; communications were interrupted to a considerable extent; and some compartments at and below the waterline were flooded by water which came in from above, but none of the main compartments were affected to such an extent that the entering water could not be handled by the pumping arrangements provided. In short, although the ship had lost a certain amount of her margin of safety, due to decreased buoyancy and stability, and her speed had suffered on account of increased resistance due to her greater draft, she was entirely capable of resuming action after adjustments to her steering gear.

The *Marlborough* was another example of a battleship continuing in action after receiving what we were inclined formerly to consider would be a disabling attack. This vessel although of the "Dreadnaught" era, has not what is now considered a highly efficient form of protection against torpedo attack, yet, after being struck by a torpedo, resulting in the flooding of a number of compartments, which produced a list of about 7 degrees, the vessel continued in action at a speed of 17 knots.

Similarly, the German battleship *Ostfriesland* (of the "Dreadnaught" era) was struck by a torpedo which produced some flooding, but the vessel was otherwise unaffected and continued on with the German Fleet.

No other British battleships received any considerable amount of punishment, but three of the modern German ships of this class received, respectively, 7, 7 and 13 hits from major caliber guns, but none of them were disabled or even damaged to an extent sufficient to prevent them continuing in action. The *Markgraf*, which was struck 13 times, is a particularly illuminating example of the amount of punishment which a modern heavily armored ship can stand. The only damage affecting the efficiency of the ship was the cutting of the communications from the masthead fire control positions, and this only resulted in shifting the control to the lower armored station provided for this purpose. The casualties on this ship were likewise remarkably low, as there were only 8 dead and 9 wounded, or only a little more than one casualty for each major caliber hit.

One particular class of hit of special interest to American designers is that in which turrets or their barbettes have been hit. Taking the case of 4 British and 4 German vessels which suffered heavy damage, it is found that out of a total of about 116 hits, 19, or 16.5 per cent, were on turrets or barbettes, of which 16 were struck. Of this number, 4 were completely put out of action and one gun in each of four others was disabled, while the remaining 8 escaped without serious damage. In other words, out of 66 big guns carried by these ships, the emplacements of 32 were struck, but only 12 were sufficiently damaged to prevent their future use. This comparatively low proportion of casualty in the major offensive armament, together with the demonstration of the ability of the mechanism of a turret to continue to function even after the turret has had a direct hit, appears to dispose of the argument of "too many eggs in one basket" so frequently advanced against the American three-gun turret.

Turning to the damage sustained by the battle cruisers, one's attention is naturally taken first by the tragic loss of the three great British vessels of this type. Although in one case the Germans claimed a torpedo hit on one of them, it is generally accepted that the loss of all three was directly attributable to gunfire, but the immediate cause of the loss in each case is still, and always will be, shrouded in mystery. It is, of course, known that each one sank in an appallingly short interval of time and that in each case at least a portion of the magazines blew up. The mystery lies in the immediate cause of the magazine explosion. Many different explanations have been advanced, but all of these affect details of design rather than the general characteristics of type. There seems little doubt that one of two things happened: German shell either entered the magazine through penetration of the protective deck, or, having pierced turret or barbette and exploded, flame was communicated to the magazine along the path followed by the ammunition from magazine to gun. From the fact that in the case of the British ships that survived, there was only one case of penetration below the protective deck at any part (no harm resulted from this), it would seem to be highly improbable that the three battle cruisers were all sunk by protective deck penetrations directly over the magazines, and not very probable that any one of them was so sunk. We must not permit our judgment to be swayed too largely by this particularly spectacular phase of the battle. Just as in the case of the battleships previously referred to, the remaining battle cruisers on both sides demonstrated ability of modern ships of large size to withstand heavy punishment without losing their fighting efficiency. The battle cruiser type is essentially and unavoidably less thoroughly protected than the battleship type. This greater vulnerability must result in greater loss of the battle cruiser type, other things being equal; but in the Jutland fight the battle cruisers were engaged much longer and much more severely than the battleships, so that a greater percentage of loss of this type should have resulted even had their protection been equal to that of the battleships. A notable fact in regard to the modern ships, both battleships and battle cruisers, on both sides, is that not a single one experienced a disabling casualty to its machinery, either as a result of damage from enemy fire or as a result of engineering breakdown. In the case of one British ship and one German ship, fires were drawn from under the boilers in one fireroom, due in each case to leakage from adjacent compartments, but in each case this leakage was controlled by the pumping plant provided for the purpose. Leaving out the three lost battle cruisers, for which no data is available, the dozen large ships in the two fleets which bore the brunt of the punishment were hit a total of about 150 times by large caliber shell, or an average of more than 12 times each. Only one of these dozen ships, namely, the German battle cruiser *Lützow*, sunk as the result of the damage received. Even this vessel sank only after 6 hours. She had received 17 large caliber hits and one torpedo. She continued to try to make the best of her way to port, but the struggle was given up about one o'clock in the morning; her crew was taken off by destroyers and she was finally sunk by a friendly torpedo.

The results of the battle, as a test of the defensive qualities of capital ships, show that in the entire action only 4 modern armored ships, all of them of the battle cruiser type, were lost as a result of the action. This was out of a total of 14 engaged and at least 7 out of the remaining 10 survived heavier punishment than most designers in pre-war days would have considered possible.

Before the war there were two distinct schools of Naval thought in regard to the main armament for the largest fighting ships. This difference of opinion existed internally in probably every navy, but internationally the American and British Navies represented the "Big Gun" advocates, as is shown by the fact that in the former we find successive increases from 12 inch to 14 inch to sixteen inch, and in the latter from 12 inch to 13 and a half inch to fifteen inch. On the other hand, the Germans adhered for a number of years to the 11-inch gun and increased their caliber to 12 inch with apparent reluctance, and a larger caliber did not appear until close to the end of the war. There were undoubtedly excellent theoretical arguments on both sides of this contention. Even now the argument cannot be definitely settled in terms of absolute material results, for too many other factors, which cannot be eliminated, enter into the problem. A convincing answer, however, appears to be provided in the very decided trend of German Naval opinion since the Battle of Jutland. Practically every report from German sources and every German publication bearing on the Battle of Jutland lays stress on the superiority in range and accuracy of the British 15-inch guns. Even if no definite material advantage for the larger caliber gun could be established, here appears to remain a marked moral superiority on the side possessing the biggest guns. This, of course, only confirms the previous views and policies followed in our service.

Summing up, therefore, we find that four outstanding facts of interest to the designer appear to emerge from the smoke and flames of the battle:

First. The value of armor protection.

Second. As a corollary to this, the necessity for the maximum number of major caliber guns; for, if the modern ship can withstand great punishment, we must, for purposes of offense, provide a sufficient number of guns to inflict a degree of punishment which will be fatal.

Third. The tactical value of speed.

Fourth. The futility of subjecting older ships to the attack of modern weapons.

In other words, the value of each one of the three major elements entering into capital ship design was demonstrated and it cannot be said that any single one has emerged with an importance transcending that of the others. If, however, one must choose among them, the consensus of opinion will probably attach more importance to protection than before the battle. This arises largely from two causes:

1st. The deep impression on the human mind by such an outstanding tragedy as the almost instantaneous loss of the three great British battle cruisers.

2nd. The impression that German ships, generally speaking, stood punishment better than the English. Admiral Von Tirpitz has been reported to have laid down as the fundamental principle of German design: That vessels before everything else must float; that they must not sink, and if possible, not even list, and that all else is of secondary importance.

This emphasis on the feature of protection is shown already by the intensified and successful efforts of both the British and the American Navies to perfect an efficient form of torpedo protection. In this connection, I think I can safely say that both services have solved this problem so far as the torpedo has been developed to date. It is also interesting to know that during the war the two services frankly and fully compared their solutions of this problem, and that although the solutions differ radically in details, they do not differ much in underlying ideas and both are believed to be successful in result. This emphasis of the protective feature

is further shown by the fact that our battle cruisers, whose construction was delayed, due to the necessity for our concentrating on the construction of torpedo craft and merchant vessels during the war, have been re-designed and given much heavier and more complete protection than was originally contemplated, accepting at the same time the slight decrease in speed necessitated thereby. We find precisely the same influence in the case of the latest British battle cruiser, the *Hood*, which was laid down shortly after the Battle of Jutland and in which we find more than a 50 per cent increase in size as compared to their *Renown*, which I have previously referred to, an increase of protection almost to a battleship standard and a decrease in speed.

Turning to the lighter craft used in the Battle of Jutland, it will be found that at several critical times during the engagement both sides used their light cruisers and destroyers to obtain a tactical advantage. Each side likewise used craft of this character to repel the attacks of similar vessels of the enemy. Although the material effect was small, there being probably not more than six torpedo hits on the large vessels of both sides, the necessity for their use is clearly demonstrated not only by their success in obtaining certain tactical advantages, for which they were used, but also in the demonstration that if either Fleet had been without these light craft, the torpedo casualties inflicted on the big ships by the light craft of the side possessing them would have been enormously greater. The losses of light cruisers and destroyers on both sides were heavy in actual number, but not in proportion to the total number engaged, as will be seen from the following table:

	Light Cruisers		Destroyers	
	No. Lost	No. Engaged	No. Lost	No. Engaged
British	0	26	8	78
German	4	11	5	77
Total	4	37	13	155

Submarines played no direct part in this battle, and it is reliably established that neither Fleet was accompanied by submarines, nor were there any submarines even within striking distance of the scene of action.

Similarly, aircraft played no part in the action, although it is understood that it was part of the German plan to utilize Zeppelins for scouting purposes in connection with the sortie of the Fleet and that this was only prevented by unfavorable meteorological conditions on the 31st of May. On the following morning, however, German aircraft were out over the North Sea and were undoubtedly of some small assistance to the German Fleet in insuring their safe withdrawal to their harbors.

Passing once more to the general phases of the war, we come at once to the outstanding feature of the war at sea, the submarine campaign and the methods adopted to combat it. Now that the veil of secrecy has been lifted we all know how close the German submarine campaign came to being an outstanding factor in the final result. Without entering into the legality and ethics of the German use of the submarine against merchant shipping, which all thoughtful and enlightened men join in condemning, we cannot escape the fact that we must in the future be prepared to find the submarine playing an important part in attacking and throttling enemy commerce, even on their own coasts. This is indicated by the result of the discussion at the Peace Conference when the world at large was so incensed by the barbarous methods used in the German submarine campaign that proposals were seriously put forward to abolish the submarine entirely by international agreement. This proposal, however, was

wisely not adopted, for, so long as the possibility of war remains, progress of science and engineering and their application to the art of war cannot successfully be throttled unless there is complete unanimity of sentiment throughout the civilized world. The use of submarines during the war has led to placing very great emphasis on the value of radius of action of these vessels, and with radius of action there must go hand in hand improvements in the living conditions on board, so that the physical endurance of the personnel may be sufficiently conserved to permit it to make full use of the material capabilities of the vessel. Both of these elements, even without the usual and concurrent demands for higher speed and greater offensive power, inevitably lead to increased size, except for a limited class of small boats, which, due to a particular strategic situation, such as that occupied by the Germans on the Belgian Coast, makes it possible to use with good results a large number of submarines of small size and limited speed and cruising radius. The technic of mine-laying has, during the war, so kept pact with the strategical and tactical demands for the use of this weapon, that the demonstrated practicability of laying them on the enemy's coast by means of submarines must in the future be taken into account, but this does not affect the general characteristics of the type, as the mine-laying feature can easily be substituted in whole or in part for the torpedo armament. Although the submarine was throughout the war something of a disappointment in the actual results which it obtained in inflicting loss or damage on the fighting ships of the enemy, its indirect effect on the freedom of action of the main fighting fleets was so considerable that the problem of the development of the so-called fleet submarine is still with us and must be solved largely from theoretical and engineering considerations, rather than from direct experience in action. Another use of the submarine, not largely foreseen, which developed considerable importance during the war, is that of scouting. It has been conclusively demonstrated that these underwater craft form one of the most valuable assets to a navy in obtaining and transmitting information in regard to the movements of the enemy's forces.

War experience developed and emphasized certain facts regarding submarines as a type which are very important from the point of view of a designer, and even more important from the point of view of those who have to determine the constitution of a navy. The submarine is essentially an instrument of stealth. Once detected, it must take refuge in the depths where, for any design yet known, its offensive powers become nil, and to the depth charge or explosive bomb developed during the war it is exceedingly vulnerable. In other words, once detected and accurately located, a submarine is at the mercy of a surface vessel. While detection devices, in spite of the enormous effort expended upon them during the war, did not reach perfection, they made much progress and will undoubtedly be steadily improved as time goes on. If we had today an accurate device which would locate a submerged submarine with reasonable approximation several miles off, and with accuracy when one or two hundred feet directly under the surface vessel, the submarine would be already obsolete as a weapon of war. While we may never reach this ideal, and while the submarine may be given offensive features to enable it to deal in some fashion with the surface vessel from beneath the surface, the submarine is essentially a vulnerable, and, if I may so express it, a precarious type; is necessary today and probably will be for many years to come, but could not be relied upon as the main feature of a navy. We read at times of proposed submersible battleships and other such imaginations, but the experience of the war does not seem to indicate this as a probable future development even if mechanically possible.

On this same subject Sir Eustace d'Eyncourt, the Director of Naval Construction for the British Admiralty, very recently stated his views in the course of a paper presented before the British Institution of Naval Architects. He said:

"A good deal has been written and talked of lately about the surface Capital Ship being dead and the necessity for submersibles. But with our present knowledge it would be quite impossible to design a submersible ship which on the same displacement and cost had anything like the fighting qualities on the surface, which are possessed by the *Hood* (the latest British Battle Cruiser). Every ship is a compromise, and if in addition to the ordinary qualities of a battleship, she is required to submerge, or even partially submerge, a very considerable percentage of weight has to be added to give her this additional capability of submergence. She becomes still more of a compromise, and the added weight must detract from the fighting qualities of the ship when on the surface, so that whatever is done, other things being equal, the submersible ship must be inferior to a surface ship in an ordinary action. There are many difficulties of details in the design of a submersible battleship which would take too long to go into fully now, and although there is no doubt that submarines are capable of great development, a little thought will make it clear to anybody that if naval warfare is to continue, the surface ship of the line must still hold the field as the principal fighting unit of any great navy."

Considering types of war vessels existing at the commencement of the war, the position of the Destroyer has been enhanced perhaps more than that of any other, and this has been brought about by our experience in its use against the submarine. As mentioned above, in discussing the results of the Battle of Jutland, the Destroyer has established its indispensability for use with the Fleet, both to attack the enemy and to protect its own capital ships. This use, however, was foreseen and provided for to at least a limited extent in all of the principal navies of the world before the war. It was not, however, foreseen that this type of vessel would be required in undreamed-of numbers to protect the sea lines of communication from the lurking underwater enemy. During the first three years of the war, it had already been found that the destroyer was the most efficient type of vessel for hunting down and destroying submarines, and for convoying or protecting a particularly valuable transport or cargo ship. In the spring of 1917, however, the losses of merchant vessels had reached such an alarming rate that the responsible authorities recognized that a new and radical method of protection must be adopted. It was then that the convoy system was put into effect, and soon proved its efficiency to a degree which could hardly have been foretold. It became then imperative that convoy should be provided as nearly as possible for every ship approaching England and France. The only available type of vessel which could perform this very arduous service, requiring many days continuously at sea in all kinds of weather, frequently at very high speed in order to accompany high speed transports, was the destroyer. This demand placed a tremendous strain on the resources of the Allies in this type of vessel, and it is now a historic fact that the United States Fleet was stripped of its destroyers which were sent to the war zone to perform this service, and that British destroyers were detached from the combined British and American Battle Fleets, upon which we depended to maintain our command of the seas, until that Fleet was actually seriously inferior to the German Fleet in destroyer strength. From our entrance into the war the United States Navy concentrated upon destroyer building, its destroyer construction undertaken during the war being on a scale never

before considered possible. It is a matter of congratulation that this has resulted in our now possessing a fleet, built or to be completed this year, of more than 300 modern destroyers of the most efficient type. In regard to the effect of the war on the characteristics of destroyers, the principal demand has been in the same direction as in the case of submarines, namely, for greater cruising radius and increased shelter and comfort for the personnel. Whereas, during the greater portion of the time of actual hostilities, convoy was provided for transports and cargo vessels only in the so-called Submarine Zone, extending 300 to 400 miles off the European Coast, it had become evident before the Armistice that as soon as we had sufficient destroyers for the purpose, escort would have to be provided, at least for the most important groups of vessels, entirely across the Atlantic. This was brought about by the ever-increasing tendency of the German submarines to operate farther afield and by the approach to completion of a very large type of cruiser submarine, which it had been known for some time was under construction in Germany in considerable numbers. The later United States destroyers would have been prepared to cope with such submarines, as the size of their guns had been increased from 4 inches to 5 inches. To obtain these increased qualities without considerably increasing the size of the boats, which was of course undesirable under the emergency demand for quantity production, meant the acceptance of a small decrease in speed. This we could accept with equanimity as our destroyers were already somewhat superior in speed to the latest types of corresponding size abroad.

The necessities of the anti-submarine campaign brought about new uses for several existing types of vessels, and the development of several new types. It had always been contemplated that fishing trawlers, drifters and other small vessels of similar type could be used in time of war as mine sweepers and tenders. With the development of the depth charge, a bomb containing about 300 pounds of high explosive with a detonating mechanism, which functioned only when it had sunk to a certain predetermined depth below the surface of the water, it became evident that any small type of vessel possessing the necessary seagoing qualities could be usefully employed against the submarine. As a consequence, this became the principal use to which these small fishing boats were put during the last year and a half of the war. They could not, of course, perform the high seas functions of the destroyer, but they proved most efficient for hunting operations and for coastal convoy purposes. The esteem in which they were held is shown by the fact that in the summer of 1917 the British Navy put in hand a construction program of more than 500 of these little craft. The limitations on the use of the fishing boats and the limitations on the production of the destroyer, due to its large size and cost, resulted in the development of intermediate types which would give good seagoing qualities combined with a speed comparable to the surface speed of the submarines themselves, and at the same time sufficiently small and simple in construction to permit of their production in large numbers. The British patrol boats and the United States Eagle boats are the principal examples of this type. The latter is really a small destroyer of 200 feet in length and 600 tons' displacement, having a good cruising radius and a speed of 18 knots and carrying an armament of two 4-inch guns with unusually good command and a large number of depth charges, together with the various devices for dropping or throwing these bombs. The British also developed and turned out a considerable number of a somewhat larger type, which were known as "Sloops," which were given a slower speed but a larger cruising radius, together with a more robust

type of construction and special features to insure their buoyancy in case of damage by torpedo. All during the war, as previously referred to, the best scientific talent, both in this country and abroad, was making every endeavor to perfect devices which would permit a vessel on the surface to hear a submarine moving below the surface. Various types of these so-called listening gears were developed and some attained a sufficient degree of success to exercise a considerable influence on the development of types of vessels from which they could be used with the maximum of efficiency. It was in fact the development of these devices in America which led to the laying down of our Eagle boats, and the machinery of these boats was designed with especial view to quick starting and stopping, so that internal noises should not in any way effect the use of the listening devices. Even before our actual entry into the war, it had become evident that it would be necessary for us to produce, in the minimum of time, the maximum number of vessels of every type which could be utilized against the submarine. This led to the planning of our program of sub-chasers. Earlier in the war, the British had purchased in this country over 500 gasoline-driven wooden hull boats of 85 feet in length for general coastal use. Their experience indicated that there was a distinct field of utility for vessels of this class, but that they should be of somewhat larger size with better sea-keeping qualities. In order, therefore, to profit by their experience and at the same time to utilize the considerable resources in this country for the construction of small wooden hull vessels, resources which were not required in the accomplishment of any of the various other war programs, we undertook the construction, immediately upon entering the war, of 350 of these sub-chasers, each 110 feet in length, about 75 tons displacement, and having three 200-horsepower gasoline engines, giving a top speed of about 16 knots. They were fitted with special facilities for the use of various types of listening gear. They carried one small gun and a number of depth charges. In their seagoing qualities, these boats more than met the anticipations of their designers. About 200 of them crossed the Atlantic under their own power and performed most useful service in the Mediterranean Sea and on the French and English Coasts. However, these boats must be regarded as stopgaps rather than a type to be found in large numbers in a permanent navy.

Another class of operations which resulted in the development of a new type, or rather the resurrection with new features of an old type, was the Naval Operations against shore fortifications. When the Germans had occupied the Belgian Coast, it became evident that the Navy must be prepared to undertake operations against that coast, unless the Germans were to be permitted to remain in undisturbed possession, allowing them an extremely undesirable freedom of action by using the ports as bases for submarines and destroyer activities. To meet this condition and the possibility of similar conditions arising elsewhere in the vast theater of war, the British very early put in hand a number of modernized monitors, which repeated the well-known characteristics of the early American vessels of this class; that is, slow speed, the heaviest guns, armor protection, low freeboard, and small size, but added to these a modern and efficient form of torpedo protection; the last named really forms the *sine qua non* of the modern monitor, for it must of necessity operate off hostile coasts and by its slow speed is peculiarly liable to successful attack by submarines. These monitors at intervals throughout the war carried out a series of very interesting bombardments on the Belgian Coast, which were accompanied by the use of such modern methods as spotting by means of aircraft and protection by means of smoke screens,

produced by small fast boats accompanying them. In general, however, these operations failed to produce any decisive results, and this experience, combined with that gained through the attempts by older British and French battleships to reduce the fortifications at the Dardanelles, has gone far to confirm the opinion held prior to the war that ships cannot compete successfully with shore fortifications.

Although not productive of new types, and not, strictly speaking, exercising any influence on naval types, it is not possible to pass over the development of the transport service during the war, as its operations were on such an enormous scale. The British conveyed to and fro from the various theaters of war a total of something like 13,000,000 men, but the great bulk of these was for the short distance across the Channel. The most impressive undertakings were the combination of the American and British resources, with some help from the other Allies, in transporting to Europe nearly 2,000,000 men during the war, and the bringing of them home in a period of a little over six months by the American Navy with some help from foreign sources. The enormous undertakings demonstrated that the great passenger vessels used commercially in time of peace can be quickly and efficiently converted for use as transports, and that, therefore, the naval designer need in the future only provide for the intelligent utilization of the great mass of experience accumulated in fitting merchant vessels for this purpose. As an example of the progress made in this direction in the course of the war, can be cited the fact that when some of the large passenger vessels were first fitted for use as transports, it was thought that they had been given the maximum troop capacity. After some months of experience, however, it was possible so to modify and perfect the arrangements that their capacity was increased in some cases as much as 50 per cent.

In reviewing the use of existing novel types during the war, one cannot omit reference to the active and important part played by certain types of auxiliaries. Colliers, tankers and supply ships were used to an enormous extent, but these are of such a purely merchant type that they require no especial note, except to remark that the few Colliers we had built as naval auxiliaries, with special handling appliances showed up exceptionally well. The purely naval types which demonstrated their efficiency and value were the destroyer and submarine tenders and repair ships. One or more of these vessels were stationed at each one of our principal operating bases abroad, and without them our destroyer and submarine forces would have been unable to maintain their great efficiency and high percentage of time employed in active service. Due to the shortage of shipping, it was not possible to fit out and supply an unlimited number of vessels of this type, and it soon became evident that each existing unit must be utilized to its highest degree of productivity. This led to the erection on shore at the principal bases of barracks for housing the shop operating forces, so that the ships themselves could be run 24 hours a day, using three shifts of mechanics. This development leads to the belief that in the future in certain types of operation we may be led to provide special barrack ships for carrying and berthing sufficient personnel to utilize to the full the repair facilities provided on the vessels specially fitted for that purpose.

I have previously referred briefly to the development of the new and large type of naval vessel called an aircraft carrier. In the very early stages of the war, attempts were made to attack the principal naval bases in Germany by means of aircraft, but it was found that neither the aircraft themselves nor the commercial vessels hastily fitted up for the pur-

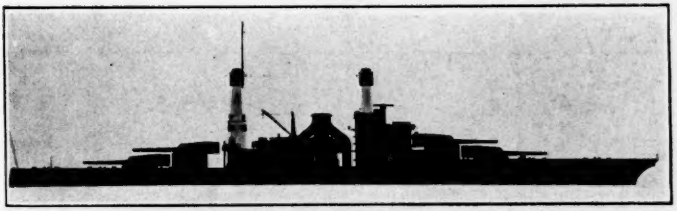
pose of carrying them were sufficiently developed to permit of success in such an undertaking. I cannot in this paper take up in detail the wonderful development in aircraft during the course of the war, but the technical development resulting in increased size and speed and carrying capacity are well known. These were quickly taken advantage of by naval designers to fit them for such purely naval purposes as scouting, fire control of the heavy guns of big ships, torpedo carrying and launching, etc.

The actual offensive use of aircraft against naval vessels was little developed during the war. Perhaps the most prominent case was that of the *Goeben* which was ashore near the Dardanelles, and for six days exposed to aircraft attack, it being stated that some 217 bombs were dropped against her. There is no doubt that there will be a great development of aircraft for naval use as a result of the war experience, and some enthusiasts have visions of navies of the air rendering obsolete the navies of the ocean.

The United States Navy, which has in its own hands the development and control of its aircraft for use over the water, should take the lead in any air naval development; but there is no doubt that, step by step with the air offensive, there will be developed a defensive. The defensive, moreover, will not be passive. We have seen in the late war how the light craft, destroyers, etc., on one side met and countered the attacks of similar craft on the other side. Had either side been deprived of its light craft, it would have been at a most serious disadvantage. Similarly, developments in the air will undoubtedly be along the line of defending the capital ship by auxiliary and offensive aircraft. The big ship which must be protected from projectiles of a ton weight falling at angles of 30 degrees, fired from ships almost out of sight below the horizon, is not yet in serious danger from bombs carried by present-day aircraft, with chances of hitting small indeed.

At the moment it appears that the torpedo plane is the most promising development; its weapon of attack is the torpedo which the capital ship must already be prepared to defend itself from, whether fired by a surface vessel or a submarine. A torpedo from a ship in the air is no more deadly than from a submarine under the surface. It seems probable that aircraft will sooner become dangerous to destroyers and the light vessels generally than to the large ships of the line. The former are more vulnerable and will be less able to protect themselves.

Even these early developments of naval uses for aircraft made it evident that they could not efficiently perform such functions with the fleet unless they could be carried with the fleet, not only on long cruises but actually in battle, with the result that special types of ships have appeared to fill this requirement. The first essential of this type is that it should be capable not only of launching aeroplanes but also of receiving them back after the accomplishment of their mission. With the present development of aeroplanes and seaplanes, the only practicable method of providing the latter requirement is the provision of an enormously large and absolutely clear deck upon which the planes can light and be brought to rest. The next requirement is that such a vessel shall have a speed sufficient to permit it to keep up with the main battle fleet when it is going into action. This means a speed of 20 to 25 knots. These qualities, together with the need for sufficient space to house and care for a considerable number of planes, together with their personnel, has resulted in vessels of 10,000 to 25,000 tons displacement. To obtain a clear upper deck requires special arrangements for funnels, navigating bridges, etc., which has resulted in the only absolutely new type of naval vessels of large size and cost which has appeared as a result of the war experience.

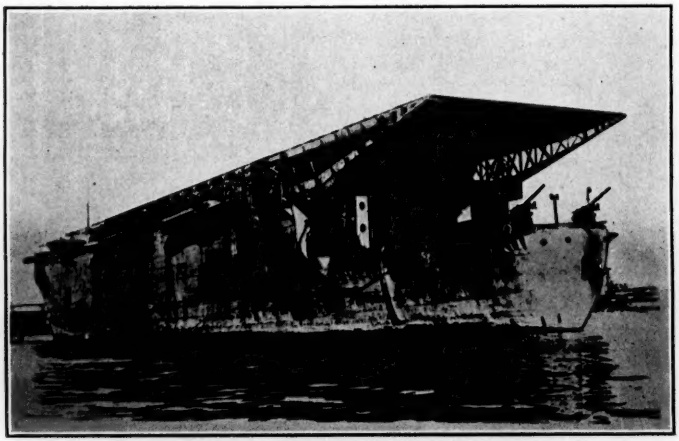


U. S. Battle Cruisers Nos. 1-6.

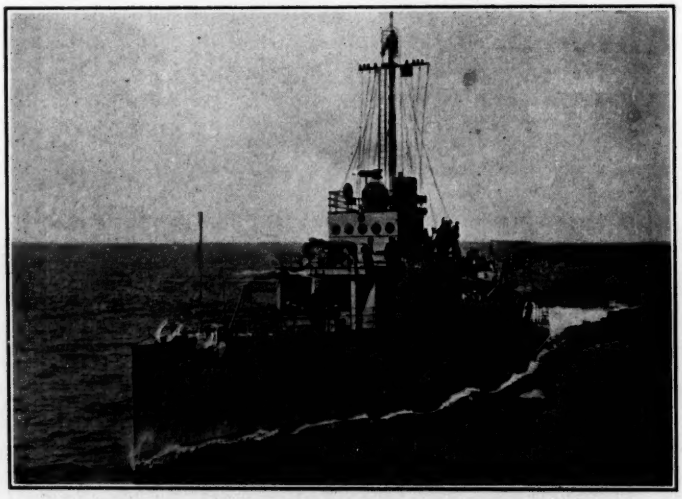
Principal characteristics:

Displacement	43500 tons	Speed	33.25 knots
Length	850 feet	Battery	8-16" and 16-6" guns
Horsepower	180000	Torpedo tubes	4-21" submerged and 4-21" above water

British Airplane Carrier "Argus."



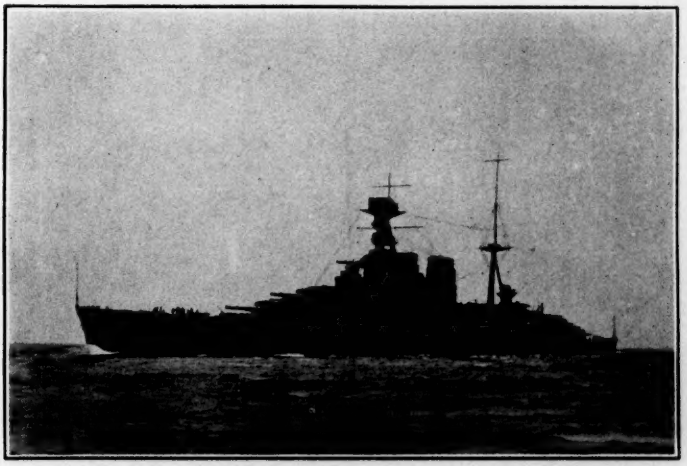
BRITISH AIRPLANE CARRIER "ARGUS."



EAGLE CLASS.

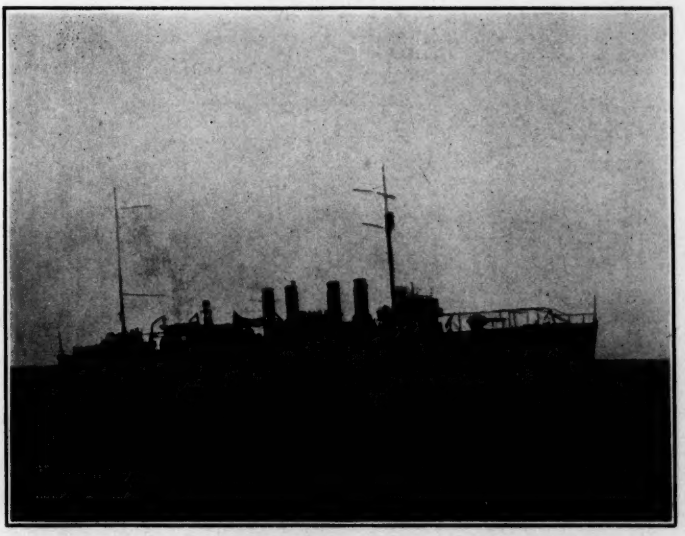
Principal characteristics:

Displacement	500 tons	Speed	18 knots
Length	200 feet	Battery	2-4" guns
Horsepower	2500	Depth bomb projector	1 Y-type



BRITISH BATTLE-CRUISER "HOOD."

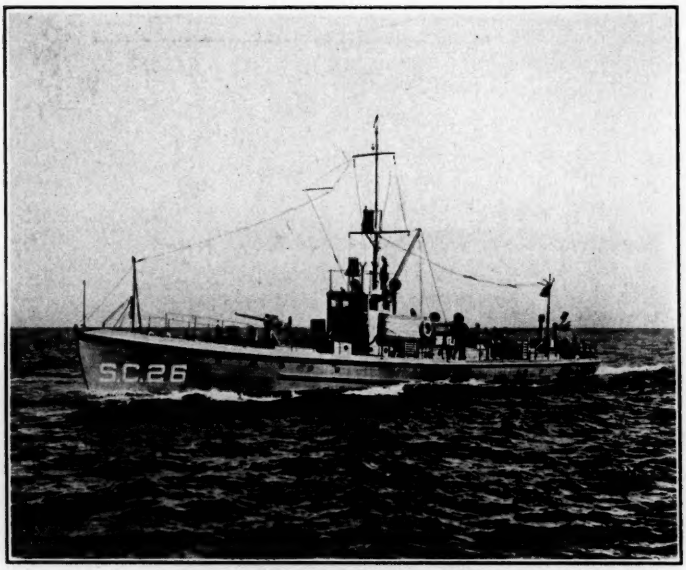
Displacement	41500 tons	Speed	31.25 knots
Length	860 feet	Battery	8-15" guns
Horsepower	144000		



DESTROYERS. 186 CLASS.

Principal characteristics:

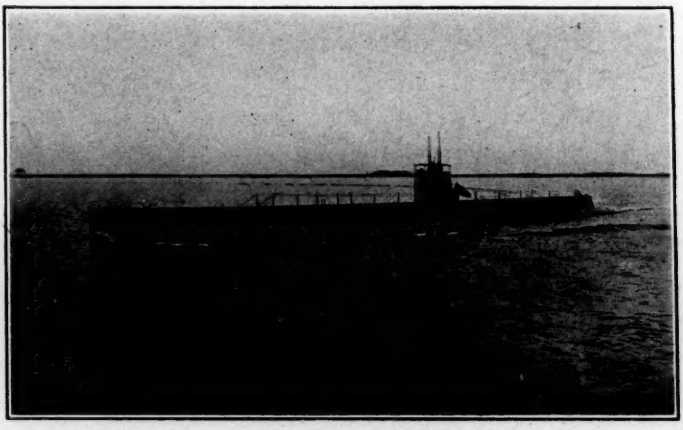
Displacement	1215 tons	Speed	35 knots
Length	310 feet	Battery	4-4" guns
Horsepower	27000	Torpedo tubes	4-21" triple



SUBMARINE CHASERS.

Principal characteristics:

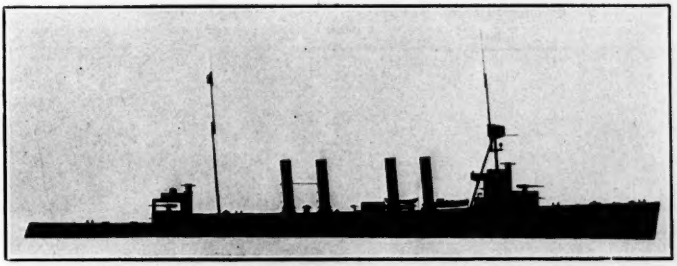
Displacement	77 tons	Speed	18 knots
Length	110 feet	Battery	1-3" gun
Horsepower	660	Depth bomb projector	1 Y-type



U. S. SUBMARINE AA1.

Principal characteristics:

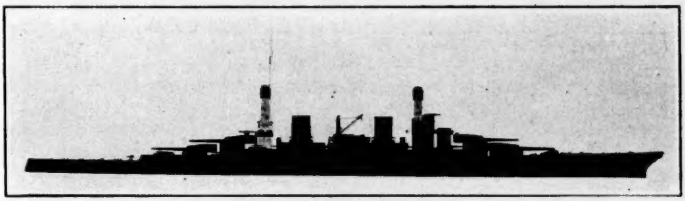
Displacement (surface)	1106 tons	Battery	1-4" gun
Length	269 feet 9 inches	2 Deck torpedo tubes aft.	
Horsepower (surface)	4400	4 Bow torpedo tubes	
Speed (surface)	20 knots		



U. S. Scout Cruisers Nos. 4-13.

Principal characteristics:

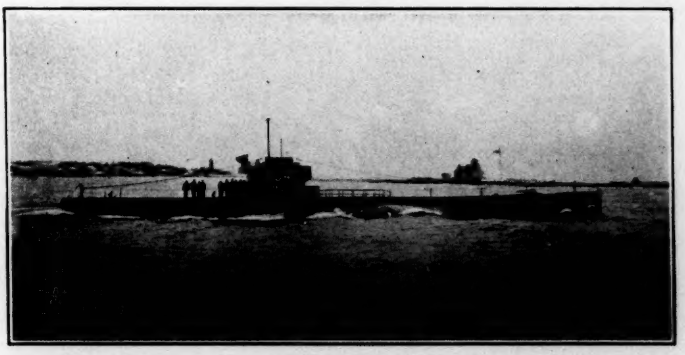
Displacement	7100 tons	Speed	35 knots
Length	550 feet	Battery	8-6" guns
Horsepower	90000	Torpedo tubes	2-21" submerged



U. S. Battleships Nos. 49-54.

Principal characteristics:

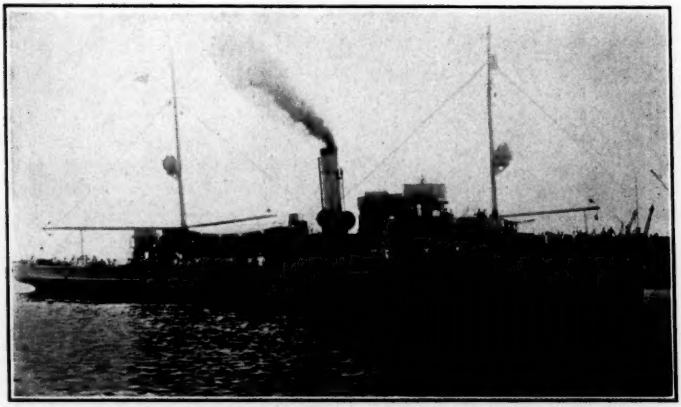
Displacement	43200 tons	Speed	23 knots
Length	660 feet	Battery	12-16" and 16-6" guns
Horsepower	60000	Torpedo tubes	2-21" submerged



U. S. Submarine S4.

Principal characteristics:

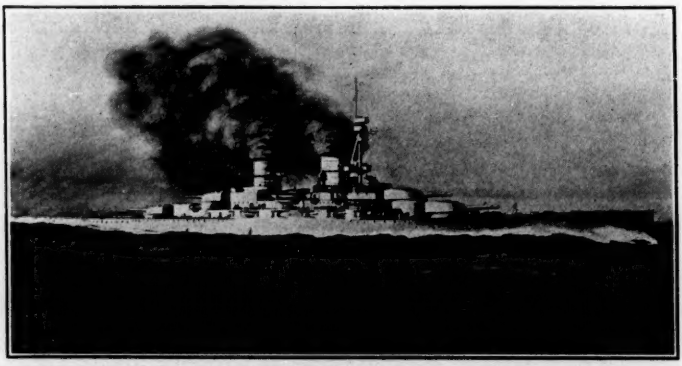
Displacement (surface)	876 tons	Speed (surface)	15 knots
Length	231 feet	Battery	1-4" gun
Horsepower (surface)	1400	4 Bow torpedo tubes	



MINE SWEEPERS.

Principal characteristics:

Displacement	950 tons	Speed	14 knots
Length	180 feet	Battery	2-3" A A guns
Horsepower	1400		



GERMAN BATTLE-CRUISER "DERFFLINGER."

Displacement.	26180 tons	Speed	26.5 knots
Length	689 feet	Battery	8-12" and 14-5.9" guns
Horsepower	63000	Submerged torpedo tubes	4-19.7"

At the other extreme among new types appearing as a result of the war, comes what have been termed coastal motor boats. These appeared more as a result of possibilities presented by modern engineering developments than as a result of the need for filling a specific naval requirement. The perfection of the gasoline motor led in the years before the war to the construction, for sporting purposes, of very light high-speed small boats. Due to the fact that they were developed primarily for racing, they were suitable for use only in comparatively smooth water and had to be handled with extreme care. A study of their possibilities by British designers, supported by the enthusiasm of young naval officers, resulted in the production of boats of 40 to 70 feet in length and capable of speeds from 35 to 45 knots an hour, each carrying from one to three modern torpedoes, and with the hulls constructed on such scientific principles that they could go to sea in comparatively rough weather, and could be hoisted on board light cruisers or other types of naval vessels. These little boats performed splendid service off the Belgian Coast, and the tale of their operations forms one of the most exciting chapters in modern naval annals. But the most spectacular, and at the same time valuable service performed by boats of this type during the war, was the daring penetration by the Italians into a fortified Austrian harbor where they sank a battleship lying at anchor. Later, in operations against the Bolshevists, a small British flotilla penetrated to the inner harbor of Kronstadt, where they succeeded in sinking two battleships and two other large vessels.

I have several times, in the course of this paper, referred to the results experienced when war vessels of older types are subjected to attack by modern weapons. During the war there were sunk by hostile action 21 pre-Dreadnaught battleships and 27 armored cruisers; of this total of 48, 11 were sunk by gunfire and 37 by mine or torpedo, only a single explosion in nearly every case being necessary to inflict the fatal damage. It is only necessary to refer briefly to such incidents as the sinking of the British battleship *Formidable*, the three cruisers *Cressy*, *Aboukir* and *Hogue*, the loss of four old battleships at the Dardanelles, the sinking of the *Gneisenau* and *Scharnhorst* off the Falkland Islands, the loss of the British *Hampshire*, and the American cruiser *San Diego* as the result of striking a single mine, together with numerous other incidents of similar nature, to show that such vessels as these, most of which were commissioned within ten years immediately preceding the war, are totally incapable of withstanding the terrific effects of present-day gunfire and torpedo attack. This showing is particularly impressive when compared to the demonstrated ability, as discussed above, of the most modern vessels to survive severe and repeated attacks. These qualities of resistance and defense can only be provided on vessels of large dimensions and displacement. The necessity for retiring these older types was well demonstrated by the fact that except for a few used for special purposes, both the British and the Germans had placed most of their older capital ships out of commission before the war had run its course.

To sum up, therefore, the experience of the war, so far as it can be grasped to date, has resulted in demands in the case of every existing type of war vessel which can only be met by increased size and cost. It has resulted in the introduction of only one new type of major importance, namely, the Aircraft Carrier, but it has introduced a number of small types which will probably survive but will not be constructed in large numbers in times of peace, as they are peculiarly adaptable to being produced quickly in large numbers after the emergency of war has arrived.

Although we must conclude that the present tendency is toward increased size and cost, one cannot overlook the fact that this very tendency, under the present financial, economic and political conditions in the world, may actually result in the long run in the disappearance from future building programs of these very types and the substitution for them of smaller and cheaper units made possible by new developments in science and engineering. To meet this condition there never was more need than at the present time of vision and imagination on the part of the fighting forces afloat and the naval designers ashore, for that nation which can develop the weapons which will render obsolete the present great ships and can substitute for them a smaller and cheaper unit capable of defeating them will win in the new era the command of the seas, which this war has shown is so all important to ultimate victory.—"Journal of the Franklin Institute," August, 1920.

DEVELOPMENTS IN NAVAL DESIGN.

On the occasion of his recent visit to the industrial centers of Yorkshire, Admiral of the Fleet Lord Beatty made an important statement relative to naval policy. Speaking at Sheffield, he said that the history of the British Navy acquitted it of any taint of aggression, and was a sufficient guarantee that its powers would be exercised for the benefit of all those who used the seas for lawful purposes. Since the war, he proceeded, there had been no new construction; but ships did not last forever, and progress in science and in technique combined to shorten the "life" of a man-of-war. The Admiralty, however, took the view that we could afford to pause before resuming naval construction. The policy of the moment was to investigate the problems of war, and to assimilate and co-ordinate the lessons derived from experience, so that when the time came, as come it must, to turn those lessons to a useful purpose, they should be applied with wisdom and understanding. So far as facilities for experimental and research work were concerned, the Navy was better equipped today than it had ever been before. He concluded by deprecating the wild and fantastic theories which had lately been propounded in certain quarters, "where surprise is felt that we are not today constructing big ships which would dive beneath the waves one minute and ascend into the clouds the next." The First Sea Lord's speech is a much needed reminder that our naval commitments did not terminate with the conclusion of peace. That we are able to postpone for a certain period the laying down of new warships is due, not to any fundamental change in the principles of national defense which hitherto have impelled us to maintain a supreme Navy, but simply to the fact that our present margin of strength suffices to meet the requirements of the immediate future. Sooner or later, however, this margin will disappear—already it is shrinking visibly—and when that occurs it will be the duty of our naval authorities to submit a new shipbuilding programme. Meanwhile the Admiralty, as the First Sea Lord assures us, is utilizing the pause to determine what modifications in ships, machinery and weapons may be indicated by war experience. It is quite clear that the present Board is in no mind to dispense with the battleship altogether. Its views on the question were set forth in the First Lord's memorandum circulated on March 12th. This document stated that the Naval Staff, having examined the question with extreme care profoundly dissented from the opinion that the battleship is dead and that submersible and air vessels are the types of the future. "In our opinion," it was added, "the capital ship

remains the unit on which sea power is built up. So far from the late war having shown that the capital ship is doomed, it has, on the contrary, proved the necessity for that type."

We may, then, assume that capital ships will form part of the new naval programme to be introduced when circumstances render it expedient, the more so because it is in this type that our lead is rapidly diminishing by reason of competition abroad; but no one outside the councils of the Admiralty is able to forecast the characteristics of our future ships. It is commonly supposed that H. M. S. *Hood* represents the last word in British naval design. This is an error, for the Assistant Chief of Naval Staff, Captain Sir A. Chatfield, has told us that if a new ship were to be laid down immediately it would not be a second *Hood*. He admitted that naval opinion no longer attached to high speed the importance that it did before the war, and that substantial protection was now considered an indispensable feature of every ship intended to lie in line. It would, however, be premature to conclude from this that the battleship of the future will be smaller and cheaper than the latest existing types. True, the demand for great speed has materially contributed to the enormous growth in dimensions, and when, as in the case of the *Hood*, that demand is coupled with a heavy armament and complete protection, it inevitably leads to huge displacements. But if the naval tactician is ready to forego high speed, it does not follow that he will consent to part with the extra percentage of displacement necessitated by installing high-powered machinery. On the contrary, he is more likely to resist a reduction in size on the ground that the weight saved on machinery can be profitably utilized by strengthening armament and protection. Nor would such an attitude on his part be unreasonable, for it is certain that the standard of offensive and defensive power, as represented by the *Hood*, will have to be raised if our future designs are to bear comparison with the best foreign ships. A "modified *Hood*," mounting the same armament as that ship and embodying the same system of protection, but with a speed of 25 knots instead of 31, might be built on a displacement of 32,000 tons, as against 41,200 tons; but if an extra pair of guns and a few extra inches of armor were postulated the figure would probably rise to 40,000 tons, if not more. As evidence that high speed is not necessarily the capital factor in determining size, we may instance the new American battleships. The *North Carolina* is not a particularly fast ship judged by modern ideas, for her machinery is estimated to develop 60,000 shaft horsepower for a speed of 23 knots; yet she displaces no less than 43,500 tons, or 2,300 tons more than the *Hood*. In this case most of the weight has gone into artillery and armor. The *North Carolina* is to be armed with twelve 16-inch 50 caliber guns, and sixteen 6-inch quick-firers, which —counting the primary armament alone—will enable her to deliver a broadside of 25,200 pounds, as against the *Hood's* 15,360 pounds. Her belt armor is reported to have a maximum thickness of 16 inches, and all the main fighting positions to have equally substantial protection. It is obvious, therefore, that except in the matter of speed this American vessel will possess a marked tactical advantage over the *Hood*, and speed, as we have said, is an element to which British naval opinion no longer attaches cardinal value.

It is scarcely necessary to observe that we make this comparison purely on technical grounds, and with no intention of suggesting that the superiority of the American ship renders it incumbent upon us to lay down forthwith a vessel of equal power. Our purpose is to show that when the time does come to resume naval construction in this country those

whose function it is to determine the characteristics of ship types will find in contemporary progress abroad a strong argument in favor of adopting heavier batteries and stouter armor, and that in this way any saving which might have resulted from a decrease in machinery power will probably be swallowed up. We would add that capital ship design, although the most important, is not the only problem that confronts the Admiralty today. Despite the exaggerated claims preferred on its behalf, the submarine cannot be said to have revolutionized naval warfare. On the other hand, it would be futile to pretend that it will have no effect on the future development of naval types. To all appearances the anti-torpedo "bulge" will suffice to preserve the heavy ship from summary destruction by under-water attack; but in the late war, as is notorious, the hostile submarines found their most effective sphere of activity in commerce destruction. Since, unfortunately, there is no guarantee against the recurrence of this menace in a future war, the problem of providing some reliable means of defending sea-borne commerce against submersible raiders is one that urgently calls for solution. Even during the late war it was found desirable to build special types of ships for convoy duty, and these vessels, as part of an exceedingly elaborate system of shepherding, enabled us eventually to keep our mercantile losses below the danger level. But it may be doubted whether the same methods would be equally effectual against the submersible corsair of the future, which may have a cruising endurance of 25,000 miles and a very powerful armament. In such circumstances the conventional form of protection, namely, fast cruisers, would no longer be adequate to secure the safety of the ocean routes, and some special design would have to be evolved, capable of guarding a convoy against attack both from surface, and submersible raiders. It will be seen, therefore, that the authorities responsible for British naval design have many difficult problems to deal with, for the late war, so far from having imposed a check on the development of material, has given it a powerful impetus, which promises ultimately to affect every weapon in the naval armory.—"The Engineer," August 13, 1920.

NAVAL RESEARCH AND EQUIPMENT.

In nearly every proposal that we have seen with regard to the broad principles which should govern British naval policy in the years ahead great emphasis is rightly laid on the necessity of devoting a generous percentage of available funds to research and experimental work. The Admiralty have given a definite assurance that everything possible will be done in future to keep the Navy abreast of scientific and technical progress. A Department of Scientific Research and Experiment has been created under the Controller of the Navy, and steps are being taken to extend the facilities enjoyed by the service for working out problems in connection with the development of every description of naval material. For instance, experimental establishments have been attached to the technical training schools at Portsmouth, and it is well known that they have already performed a great deal of useful work in improving mines, torpedoes, and electrical apparatus. Another branch which the war brought into existence is the Anti-Submarine School, an institution of capital importance which ought on no account to be handicapped by lack of funds. The Admiralty's general scheme for promoting research looks satisfactory enough on paper, but we know from experience that these excellent projects have a way of getting quietly shelved in the course of time unless the searchlight of publicity is trained upon them at regular intervals. Next to the welfare and contentment of the personnel, we

consider an unremitting study and application of war experience to tactics and material to be the most important present-day duty of the naval administration.

It would be absurd to pretend that the weapons and material we possessed at the outbreak of war were as perfect as they might have been. The German torpedoes, mines, and projectiles were superior to ours, and it is no use denying that the efforts of our commanders at sea were often stultified by the indifferent material they had to work with. Apparently there had been too much theory and too little experiment. It seems almost incredible that the deficiencies of our armor-piercing shell—to mention one notorious example—were not discovered until the day of the battle. The suggestion that the projectiles were the best that could be manufactured at that period is preposterous; moreover, it is disproved by the fact that as soon as the failure became known we at once set about producing shell of infinitely better quality, although the enemy never gave us an opportunity to test them upon his ships. In this case no doubt departmental conservatism was at the root of the trouble, but a contributory cause was the short-sighted policy that refused to spend money on practical trials. Before the war we often drew attention to Germany's lavish expenditure on the testing of her naval weapons. It was the invariable practice there to make exhaustive tests of every class of material before finally accepting it for naval purposes. No new gun was adopted until it had been tried under conditions resembling as nearly as possible those of actual war. New projectiles were fired against targets representing the most strongly armored ships of the day, and if they failed to do all that was expected of them an improved type was at once designed. In this way the Germans had evolved a shell that would carry its powerful bursting charge through the thickest armor, while we had no thoroughly reliable A. P. shell until the third year of the war. The same policy of striving for maximum efficiency, regardless of trouble and cost, was pursued in the development of gunnery, torpedoes, mines, and systems of armor protection. Of course, it was a costly business. Between 1908 and 1914 Germany is said to have spent four times as much money on this sort of thing as we did, but her method proved in the end to be the most economical.

In the light of present knowledge it can be asserted with confidence that had all our material been as technically efficient as Germany's was, the task of crushing her at sea would have been enormously simpler and cheaper. Experience that might have been purchased in peace time for a very modest sum had to be hurriedly acquired in war at a terrific cost. It is not enough that the Navy has learned its lesson in this respect; public opinion also needs to be reminded that the mere voting of money for men and ships is not the whole of its duty to the service. It is for the Admiralty to insist on proper financial provision being made for the continuance, on a scale of reasonable dimensions, of the research and experimental work that was in full swing towards the end of the war. Unless this is done the priceless experience we gained from the war will be wasted. As the Admiralty have said, "To stop pure research work altogether at this moment would be a retrograde step, and might conceivably have a serious effect ultimately on development of types of ships and weapons, and on economy generally." Adventage might profitably be taken of the pause in new construction to press for an increase in next year's vote for "scientific research and experiment," which in the current estimates stands at about £285,000. This sum is so obviously inadequate as to suggest that the old penny-wise pound-foolish system is already in force once more.—"The Naval and Military Record," Aug. 18, 1920.

NAVAL ARCHITECTURE IN AERONAUTICS.*

By JEROME C. HUNSAKER, Eng.D., COMMANDER, Construction Corps, U. S. Navy.

Introductory.—As an American, I am very pleased to have been asked to read the Wilbur Wright Lecture for this year, and for a moment to stand in the reflected glory of my eminent countryman. Wilbur and Orville Wright were the pioneers who blazed the trail, and made the first clearing in the wilderness. We engineers who follow later are only applying modern machinery and methods of intensive cultivation in their original field. We should, therefore, keep in mind the fact that this field is given to us in trust to keep fertile, that its yield of benefit to mankind shall not diminish. I have chosen to discuss the use of the tools of the naval architect in aeronautics, as I consider that the time has now come to use them. The naval architect is a craftsman with both artistic and scientific traditions, and the art he practices has a technique perfected by the experience of generations. It is only a few years since the Wrights gave the aeroplane to the world, but four of those years were years of astonishing activity, and the experience of those years is worth more than that of forty ordinary years. There is already a vast store of experience available which the naval architect's methods can analyze, classify and reduce to useful engineering terms.

While aeronautics as a useful art and a science is new, naval architecture is hoary with age. Noah probably considered and evidently reached a successful solution of the very problem of animal transport by sea that confronted our naval architects in the Great War. King Hiram of Tyre must have had a very fair naval architect who could fashion ships from cedar of Lebanon with a factor of safety and a range of stability adequate to cope with Atlantic storm waves. Archimedes, however, is generally recognized as the father of naval architecture. He first developed the laws of displacement and buoyancy, and is credited with the construction in 264 B. C. of the *Syracusia* of 6,000 tons—a veritable Dreadnaught of antiquity.

The naval architect practices an art with scientific methods. He applies mathematics, especially geometry, in establishing lines, displacement and stability. He applies the methods of the civil engineer in matters of structural design. In matters of resistance and propulsion he is guided by the theory of hydrodynamics. But in all of these applications, the sure and true guide has been experience. From that remote age when the hollowed-out log canoe replaced the solid tree trunk down to the days of sail and steam, the naval architect has based his new design upon his last. Factors of safety and coefficients of all kinds, used in apparently theoretical or frankly empirical formulæ, have been really factors of experience. The naval architect's problem deals with the sea, and we cannot pretend to know much more of its mysteries than that Syrian landsman who marvelled at the way of a ship in the midst of the sea. The forces of nature are still incalculable, but the design of a vessel to be staunch and safe is not such a dark and dreadful adventure. Confidence comes from experience and the naval architect's most powerful assistance comes from the scientific analysis of that experience to reduce its lessons to engineering terms.

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The naval architect has available a priceless store of learning accumulated by generations of shipbuilders which, with skill and judgment, he can make serve him. He cannot afford to lean too leavily on the past, however, and where a new type of vessel must be produced, imagination and judgment of a high order are necessary. There is an artistic side to naval architecture, and for many craft the artistic feeling or "flair" of the designer distinguishes an advance in the art from a routine product. In aeronautics I have yet to see a design representing a marked advance in the art made either without this artistic feeling for form and proportion or made wholly without reference to the lessons of the past.

General comparisons are impossible, but it seems to me that in England aircraft designers have followed the naval architect's methods more than in other countries. This is, perhaps, natural in the first maritime power of the world. In England, also, I find a very extensive application of the results of experimental research, both model and full scale, which really is experience interpreted and analyzed by scientific methods. In France I see less influence of experience and perhaps more originality of invention as shown by occasional radical departures, omitting intermediate steps of development. In Germany there was once a tendency to "professional designs" based too strictly on theory, resulting in strange and awkward structures like the Taube types. During the war something happened to reverse this policy, and we saw a series of machines developed step by step, obviously from experience. In America we have suffered from the designs of the inventor without experience and from the practical rule-of-thumb man without theoretical landmarks to guide him. On the whole, the successful designs have been produced by men of imagination and judgment applying analyzed experience with the best theoretical and engineering information available.

For very small machines the inventor type of designer has been very successful at odd times. He hits on a good solution, and, by a process of cut and try, eventually works out the faults before his patience or purse is exhausted. For large machines and airships the time and expense required are too great for cut and try methods. A large flying boat or an airship is a success or failure on her first flight. If badly over weight, unstable or out of balance there is no chance to rebuild.

In our Navy we look with suspicion on the man who is more concerned with the method of doing things than in the actual doing of them, and to avoid any misunderstanding, I must say here that I wish to make my point as to the utility of the naval architect's methods in aeronautical engineering by attempting actually to do a few things which appear to be needed at this time. This work I have thrown into appendices attached to this paper. I will not take time to read each complete appendix, but will discuss them briefly. I trust that if my technical friends will find time to look into them, they will find them useful.

ABSTRACT OF APPENDIX I.

Weight Estimation.—Both the aeronautical engineer and the naval architect risk their reputations with weight estimates. A ship must float on her designed water line and an aeroplane must fly with the wing surface provided. Serious overweight in either case marks a failure. It is only rarely that vessels are discovered to be much overweight, but, unfortunately, overweight has been all too common with aircraft. Naval architects are able to estimate weight with fair precision from unit weights gleaned from past experience, and to check this estimate by calculation from the drawings. During construction, weights are controlled by weighing every-

thing that goes aboard the ship. For aircraft, the practice of rigid weight control has not been well established either in the shop or in the drawing office. Very often construction is commenced before the drawings are completed, and during construction changes and alterations are incorporated without reference to their cumulative effect on the weight. A proposed change may be approved on its merit and not with reference to a definite weight allowance.

It is essential that before construction, or even detail design, is commenced, a weight estimate should be made in the nature of a weight allowance which shall be treated like a bank balance, and on no account be overdrawn. Such a weight allowance must be made from the general design drawings before the details are developed and necessarily is based on past experience with a similar type of construction. This is the naval architect's method, and to avoid guesswork requires extensive records and weight returns from actual work. The matter of weight estimation for various types of aeroplanes is not really such an inaccurate procedure even in the case of an apparently radical departure from previous types of construction. I have assembled published weight data for several hundred different aeroplanes and seaplanes—British, French, Italian, German and American—from the smallest to the largest, and while the returns in any individual case may be unreliable, the general trend is usually quite definite. It appears that no designer, whether using solid wood, hollow wood or metal, is getting something for nothing, and, in general, the percentage weights for machines of similar type are remarkably alike. If this conclusion be established, a designer may estimate the weights of a new design with some degree of confidence provided he has data for a somewhat similar type to work from.

The following general conclusions appear to be established:—

1. The weight of wings, struts, wires and tail surfaces amounts to about 20 per cent of the gross weight for all types.

2. The weight of body, fuselage, landing gear, boat hull, &c., trends downward from 22 per cent of gross for 1-ton machines to 15 per cent of gross for 20-ton machines.

3. The weight of power plant also trends downward from 30 per cent for small to 20 per cent for large machines.

4. The weight light for machines from the smallest to the very maximum sizes has today a lower limit at about 53 per cent.

5. For large flying boats and large aeroplanes the weight light is about the same.

6. The structural weight is high for low-powered machines and low for high-powered machines, and in general the best weight carriers show about 18 pounds per horsepower.

7. Similarly, the structural weight is high for low wing loading and *vice versa*.

8. The wing loading is found to be greater for the larger machines, reaching a maximum of nearly 12 pounds per square foot for the large flying boats.

9. It appears that all the evidence from past practice indicates that large flying boats can safely be given a higher wing loading and a higher landing speed than land aeroplanes, and, hence, have a distinct advantage as weight carriers for commercial purposes.

ABSTRACT OF APPENDIX II.

Metacentric Height.—They that go down to the sea in ships are wont to criticize a ship in an offhand manner, her wetness or dryness, her period

of roll, whether she will sail sweetly or prove crank, and other mysterious details of her intimate behavior among waves. And all this with an apparent confidence which to a layman must betoken a wisdom such as Solomon's. But there really is little mystery about it, for nearly 175 years ago, Bouguer,* the father of theoretical naval architecture, hit upon the brilliant conception of a metacentric height to serve as a measure of stability. Since that time thousands of ships have gone to sea with cargoes stowed in an indefinite number of arrangements, and millions of passengers, as well as animals, have been made violently or only mildly ill. Some ships carried sail well, others were crank; some ships proved stiff but violent in motion, others capsized. Every sort of marine disaster has occurred, and as a result an enormous store of experience has been accumulated. In nearly all such cases a knowledge of the metacentric height of the vessel has proved to be a valuable index to her behavior.

The metacentric height or distance from the center of gravity to the metacenter is the limit of the distance G m on Fig. 1 as the angle of roll $\Delta\ \theta$ from the normal or upright position becomes small. A ship is stable if there is a righting moment for any angle of heel. The initial stability is measured by the metacentric height in the upright position. If the ship be already heeled through a large angle, she is still stable if she still has a positive metacentric height. There is thus to be considered the problem of range of stability or the angle of heel permissible before the metacentric height vanishes. The period of a roll, neglecting damping, is given by the expression:
$t = \pi\ k\ /\ \sqrt{}\ (g.\ \mathrm{G}\ m)$, where k is the radius of gyration. It appears that the rolling will be quick, and hence uncomfortable, when G m is large. For an easy ship G m should be small, but not so small as to impair the range of stability. For passenger steamers G m may be made small with safety, but for warships it is necessary to provide a larger G m than the gunnery officers would desire, to provide for stability in a damaged condition. Battleships sunk in action usually capsize before going under. I have spoken so far of the "lateral" metacenter which controls the rolling of vessels. There is, of course, a strictly analogous "longitudinal" metacenter which controls the pitching.

The metacentric height is, of course, an index to the statical condition only, but for all practical purposes has served the naval architect very well. The dynamics of rolling among waves† are even more elusive than the theory of aeroplane stability so beautifully developed by Bryan‡ and Bairstow.§ And just as the naval architect proceeds to design good vessels by using his practical judgment based on experience and a knowledge of the metacentric height regardless of the mathematics of resisted and synchronous rolling, so do we find aeroplane designers producing good aero-

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* Bouguer, "Traité du navire," Paris, 1746; L. Euler, "Scientia Navalis," St. Petersburg, 1749; Atwood, "Stability of Ships," London, 1796; Chas. Dupin, "Applications de Géometrie et de Mécanique à la Marine," Paris, 1822; P. J. Moreau, "Principes fondamentaux de l'équilibre," &c., Lorient, 1830; J. M. C. Duhamel, "La stabilité des corps flottants," Paris, 1832; H. Mosley, "On the Dynamical Stability and on the Oscillations of Floating Bodies," London, 1874.; F. K. Barnes, "On the Metacentre and Metacentric Curves," "Naval Science," vol iii, London, 1850; E. J. Reed, "A Treatise on the Stability of Ships," London, 1885.

† D. Bernoulli (Prix de l'Académie des Sciences), Paris, 1757; Dupuy de Lôme, "Mem. G.M.," vol. iv., Paris, 1859; Wm. Froude, Proc. Inst. Nav. Arch., vols. ii, iii, iv, xiv, xvi, London; Rankine, Proc. Inst. Nav. Arch., vols. v, xii, London; Scott Russel, Proc. Inst. Nav. Arch., vol. iv, London; Bertin, "Les vagues et le roulis," Berger-Levraut, Paris, 1877; Reech, "Théorie du roulis, &c.," Paris, 1870.

‡ G. H. Bryan, "Stability in Aviation," Macmillan, London, 1911.

§ L. Bairstow, "Advisory Committee for Aeronautics," R. and M., 110-122, London, 1914.

Fig. 1.

W = total weight. L, L' = water-lines upright and inclined. B, B' = centres of buoyancy upright and inclined. $\Delta\theta$ = angle of inclination. M = metacentre. G = centre of gravity. Gm = metacentric height.
Righting moment = W.Gm sin $\Delta\theta$ = W . Gm . $\Delta\theta$.

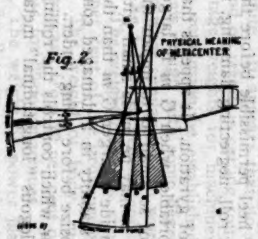


Fig. 2.

L = lift = weight = W. D = total drag. R = total air force. G = centre of gravity. ⊙ = centre of pressure. M = metacentre. Gm = metacentric height. $\Delta\theta$ increment of pitch.
Pitching moment = W . Gm . sin ($\Delta\theta$), = W . Gm . $\Delta\theta$.

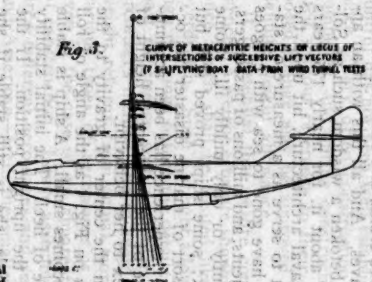

CURVE OF METACENTRIC HEIGHTS OR LOCUS OF INTERSECTIONS OF SUCCESSIVE LIFT VECTORS (F.B.I. FLYING BOAT DATA FROM WIND TUNNEL TESTS

Fig. 3.

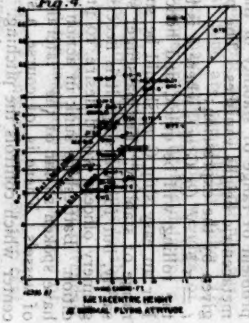


Fig. 4.

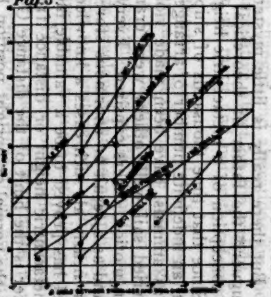


Fig. 5.

planes, using practical judgment and very little mathematics. I have yet to find anyone in a successful aeroplane design office solving simultaneous differential equations of motion.

Unfortunately, the aeroplane designer has not 100 years of experience to draw on, and there has been no ready handle on an aeroplane to seize upon like a metacentric height. Consequently, a great deal must be left to judgment, artistic feeling, comparison with other aeroplanes, and eventually to the opinion or prejudice of the test pilot. The need for some ready means for off-hand judgment of aeroplane stability and maneuvering ability has been felt for a long time. The mathematics of stability are too cumbersome for practical use, and require extensive wind-tunnel research to establish the necessary constants. It is my experience that we can build and fly a small aeroplane in less time than it takes to perform the stability calculations.

The general case of the disturbed motion of an aeroplane is not simple, but the longitudinal or symmetrical motion is two-dimensional and can be considered apart from the lateral or asymmetric motion. For the longitudinal motion, we are interested in the pitching oscillations and the criterion that such oscillations be stable. For aeroplanes of normal design, if there be a righting moment called into play by any angular deviation from the normal attitude* the pitching oscillations so produced are strongly damped. In other words, if an aeroplane be statically stable it is also dynamically stable, so far as pitching is concerned.†

My colleague, Commander Wm. McEntee (C.C.), United States Navy, suggested the application of the naval architect's metacenter to measure the statical stiffness of an aeroplane's longitudinal stability. I have assembled the data from all of the wind tunnel tests on complete model aeroplanes that I had available, and have computed the metacentric height from the observed slope of the curve of pitching moments in the following manner:—

$\Delta M/\Delta\theta$ = slope of curve of pitching moment.
And $M = W \quad G\,m \sin\theta = W\,G\,m\,\theta$, for small angles.
But $M = (\Delta M/\Delta\theta)\,\theta$.
Then $G\,m = (1/W)(\Delta M/\Delta\theta)$.

This algebraic definition of $G\,m$ has the dimensions of a length and amounts to from 2 feet to 12 feet for modern aeroplanes and flying boats. It is directly proportional to the coefficient M_w of Bairstow's notation, but immensely more easy to remember for use for purposes of comparison. It is also proportional to the center of pressure motion. To give the length $G\,m$ a physical meaning, Fig. 2 has been drawn to an exaggerated scale. It will be noted that m is the intersection of resultant lift vectors for successive angles of incidence, resolving the lift component at a line of reference through the center of gravity in the direction of motion. As an intersection, m is, therefore, dependent on the angle of incidence, and it can be shown that for large angles of incidence m approaches G. The metacentric height grows less and tends to vanish when the aeroplane stalls. This is, of course, entirely consistent with the unfortunate natural phenomenon which makes a stalled aeroplane notoriously unstable.

Fig. 3 is a graphical representation of a wind tunnel test of a model of a flying boat. It shows how $G\,m$ diminishes for larger angles of incidence until it vanishes at about 12 degrees. The metacentric heights have

* A positive value of M_w in Bairstow's notation.
† Hunsaker, "Dynamical Stability of Aeroplanes," Smithsonian Misc. Coll., vol. lxii, No. 5.

been calculated from wind tunnel tests on complete models (ex propellers) of 27 types. Aeroplanes both small and large were included, as well as float seaplanes and flying boats. We have a truly miscellaneous collection, with British, French, German and American examples, which should give a good test of the naval architect's method of classification by means of metacentric height. Designers have, in general, been giving a greater metacentric height for great chord length, which appears reasonable. Plotting the metacentric height against chord length on Fig. 4 brings this out clearly. The points group themselves about a straight line. It therefore seems possible from a knowledge of the relation of chord to metacentric height for any design to say, with some confidence, whether the machine will be more or less stable (stiff) longitudinally than the average, and whether such stability will be reasonable or abnormal.

Effect of Change in Angle of Stabilizer Setting.—Calculations of G m have also been made from wind tunnel tests in which the setting of the stabilizer has been altered. To bring out the effect of such changes, Fig. 5 has been made where G m is plotted against the angle of stabilizer setting, *i. e.*, the angle between the stabilizer and the wing chord. It will be

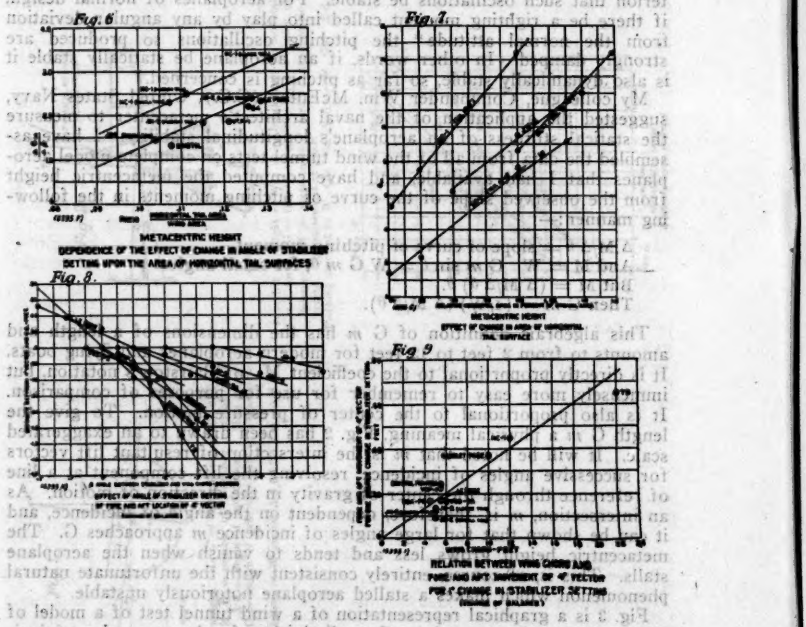


Fig. 6
METACENTRIC HEIGHT
DEPENDENCE OF THE EFFECT OF CHANGE IN ANGLE OF STABILIZER SETTING UPON THE AREA OF HORIZONTAL TAIL SURFACES
Fig. 7.
Fig. 8.
Fig 9
RELATION BETWEEN WING CHORD AND FORE AND AFT MOVEMENT OF C.P. VECTOR FOR 1° CHANGE IN STABILIZER SETTING

noted that the points fall near straight lines whose slopes are the change in G m per degree change in angle of stabilizer setting. This slope is denoted by $\Delta G\,m/\Delta\beta$ and is plotted against the ratio of horizontal tail area/to wing area in Fig. 6. It is found that $\Delta G\,m/\Delta\beta$ depends on the area of the horizontal tail surfaces in a straight line function. The slope

of each line of Fig. 5, when plotted on Fig. 6, falls near either one or the other of two straight lines which have substantially the same slope. It is to be noted from these lines that the tractor-type tail surface is less efficient than the N. C., a pusher-type tail surface, a conclusion consistent with previous experimental work. (A. C. A. R. and M. 438 and 505.)

Effect of Change in Stabilizer Area.—The values of G *m* for changes in stabilizer area for various machines, plotted against percentage of the original area, are given in Fig. 7, and it will be seen that they line near straight lines. The variation in the slopes of these lines is small and seems to be independent of the original size of the stabilizer.

Fore and Aft Movement of Center of Pressure.—In order to study the movement of the center of pressure, the 4 degree vector location, or line of action of total air force for an angle of incidence of 4 degrees, has been determined for a number of machines and for various stabilizer settings. These locations are plotted on Fig. 8. For each machine the points are found to lie near a straight line, the line for the larger machines having, however, a greater slope than those for the smaller machines. In Fig. 9 the slopes from the lines of Fig. 8 are plotted against the wing chord of the machines which they represent. The fact that all of the points so plotted lie very nearly on a straight line indicates that the movement of the 4 degree vector with change in angle of stabilizer setting is almost entirely dependent upon the wing chord. The average value of the movement of the 4 degree vector per degree change in stabilizer setting is found to be 0.033 $\times$ chord. This movement is forward if the normally negative angle between stabilizer and wing chord is increased, and *vice versa*.

In the foregoing discussion I have tried to bring out the fact that an aeroplane actually has a metacentric height which is entirely under the control of the designer. It would very much clarify our knowledge of aeroplanes if we knew the initial metacentric height the designer gave it. Knowing this, we could judge, with some degree of confidence, whether the machine is reasonably stable for its type. Further, if we knew the metacentric height as designed, the effect of stabilizer adjustment could be considered more intelligently than it is at present. The adjustable stabilizer is a very useful and convenient device for altering the balance of a machine, but it also alters the metacentric height. It is quite possible, by excessive use of this means to balance up an otherwise tail heavy machine, entirely to destroy the metacentric height and hence the stability. The tables and charts given in the complete appendix may prove useful in the consideration of such a possibility for a particular design.

ABSTRACT OF APPENDIX III.

Control Surfaces.—I doubt if there is any one part of an aeroplane which has caused more trouble than the control surfaces: rudders, elevators, ailerons. The three-rudder system of control invented and developed by the Wrights made flight possible. It is fundamental for three dimensional space. All of the experiments before the Wrights failed for lack of proper control. Consider the machines which did not really fly of Lilienthal, Montgomery, Langley and the other pioneers. As soon as the Wrights showed how to control an aeroplane, any boy could make his own glider. Yet although the fundamental nature of this discovery is universally recognized, we know little more about the design of such control surfaces than the Wrights taught. Control surfaces are proportioned for aeroplanes and airships largely by judgment and experience. There is no sure calculation in our handbooks, and the designer risks his reputation and the test pilot risks his life on many new machines. For civil

aviation it is especially important for machines sold to the general public to have adequate control surfaces. This is quite as important as to require adequate factors of safety and apparently not one-tenth so difficult. However, the areas and proportions of control surfaces are the only things not covered by specifications. We depend on the test pilot to state whether he finds the control certain and easy.

When an important feature of design is so largely a matter of judgment and feeling we look to naval architecture for an analogous problem. The rudders of vessels are made large or small, depending on the maneuverability desired. The actual design of such rudders is a matter of judgment and experience. For a merchant ship a rudder area from 1/75th to 1/100th the area of the longitudinal section of the ship is found to be quite satisfactory for ordinary steering. For warships the turning circle is a military feature, and to give quick maneuvering a rudder relatively twice as large is used. The exact size and shape of rudder to use for any design are determined from an analysis of the rudder proportions of ships of similar type whose turning circles and general behavior are known. Such mathematical theory of the turning of ships as exists is used in selecting the important variables in the problem, but the analysis results in empirical coefficients.

The naval architect's method has been applied to obtain empirical coefficients for the control surfaces of aircraft of various types. It is interesting to note that the average coefficients for very different types are practically the same. The coefficients for the individual machines vary more widely and reflect the individuality of the designers. In particular, the average for 15 German aeroplanes shows an aileron area only 8 per cent of the wing area, while, in general, the averages lie between 11 per cent and 13 per cent. It must be that the Germans did not desire a powerful lateral control.

Similar coefficients for the control surfaces of airships show less uniformity and it would appear that airship designers had not yet settled upon simple rules. However, experience with airships is still relatively limited when we consider the immense numbers of aeroplanes that have been built.

Turning now to the proportioning of the control surfaces; both experience and wind-tunnel experiment teach that the best control surfaces are narrow trailing portions of fixed surfaces. This makes for simplicity both structurally and aerodynamically. But a difficulty arises in large machines where it is necessary to balance the surfaces to relieve the load on the pilot. I know of nothing more embarrassing than to have a balanced aileron or elevator flutter violently in flight, unless it be to have the balancing portion twist off entirely.

The aeronautical engineer needs some simple rule for the design of balanced control surfaces. It is not practicable to make elaborate wind-tunnel experiments for every design and it is not safe to depend too much on judgment. In order to use simple rules, aeroplane designers must adopt forms which lend themselves to simple computations. Many of the forms of balancing in common use are, aerodynamically, entirely indeterminate. No man can calculate with confidence the force of the air spilling off a wing tip and striking an overhanging portion of aileron. There is certainly a vortex there of a most uncertain nature. Similarly, in the so-called "dovetail" method of balancing where the balancing portion of the control surface works in a recess in the fixed fin, there is a mutual reaction between the two surfaces which is highly indeterminate. The Zeppelin rudders have until recently had this form of balance, but I have noted

with satisfaction that the "Bodensee" has changed to a partially overhung type of rudder. The naval architect has long ago been through similar troubles with ships' rudders in rear of the dead wood aft, and concluded that he would use a plain trailing rudder hinged to the stern post with an underhung balancing portion porjecting into clean water. The dead wood is cut away forward of this balancing portion. Spade rudders are used where they cannot influence the dead wood or be blanketed by it. If aeronautical engineers would agree to use simple overhung balanced control surfaces, a simple calculation would serve for their design. A calculation for such control surfaces on a number of machines where the center of pressure of the trailing portion is taken at 0·3 chord length and for overhung portion at 0·2 chord length, has been made and the ratio of balancing to righting moments gives a coefficient which, for the normal case, free from blanketing or slip-stream effects, should not exceed 0·65.

To sum up, control surfaces of the usual type can be designed by use of coefficients taken from similar type machines of normal behavior with every assurance that the maneuverability of the new design will prove normal.

ABSTRACT OF APPENDIX IV.

Normand's Weight Equation (Rigid Airships).—There is nothing more profitless than an argument over a proposed design between the operating *personnel*, who are always demanding enhanced military characteristics, and the constructors, who are prone to object to change on the grounds that their pet design will be spoiled. Most likely both sides advance very strong arguments to support a particular view of the matter. But such a discussion should not rest on a basis of argument alone, else it degenerates into something resembling that ancient impasse: "Are the mountains better than the seashore." As a matter of fact, the effect of any proposed change in military characteristics can be calculated in a sufficiently approximate manner to make possible a decision based upon evidence. For rigid airships which closely resemble vessels, I propose the use of a naval architect's method for analyzing such problems due originally to that eminent French designer of torpedo craft, M. Normand, and subsequently extended and perfected by Professor Hovgaard. By Normand's method, a rapid estimate can be made of the cost in displacement involved by almost any proposed change in the ship.

In the fourth appendix to this paper, I have developed Normand's method to apply to airships by forming the so-called weight equation as the sum of the principal weight groups each expressed in terms of the independent and dependent variables of the design. This weight equation is then differentiated to exhibit the effect of a change in any of these variables and formulæ deduced, analogous to those which apply to vessels, by which a quantitative estimate can be made for the effect of such change.

An airship can be changed in two ways, by preserving similitude of form and permitting the volume to vary or by holding constant volume and changing the ratio of length to diameter. Considering the first case, the factor of proportionality N computed in the fourth appendix is about 4·5 for a ship of L.49 type. This means that an addition of 1,000 pounds to the weight of any item in the ship calls for such increase in other items, to keep the performance the same, that the total lift must be increased 4,500 pounds. For battleships N is of the order of only 2·5, indicating a much more favorable situation. The principal reason airships appear to be at a disadvantage comes from the longitudinal members of the hull structure whose weight increases as the fourth power of the length of the ship. Con-

sider now the effect of holding volume constant and changing the fineness of the ship. The longitudinal members of the hull vary in weight as the third power of the length and the first power of the diameter, while the weight of the transverse frame varies as the fourth power of the diameter. If the ship be fattened up, weight is saved on the longitudinals and lost on the transverses. But if the ship be too long originally there will result an important net saving in weight.

Finally, I have applied the method to a rigid airship of the Zeppelin type (L.49) in an example to show how practical answers may be obtained. The displacement of L.49 is assumed to be 1,940,000 cubic feet, or 129,800 pounds. If it be proposed to make a new design which shall be similar to L.49, except to have 2,000 pounds more bombs, a 25 per cent heavier outer cover, and 15 per cent more speed, the new ship must be given 13,890 pounds more displacement, or a total volume of 2,145,000 cubic feet. The net price paid in displacement is, therefore, about 6 tons.

On the other hand, if the ratio of length to diameter be reduced from 8 to 7, the ship can be built lighter, and the calculations show that a saving in the new design of nearly 5 tons is due to this change of form alone. As a final result, a new ship resembling L.49 might be built having the proposed changes incorporated, and only be slightly larger than L.49; *i.e.*, 1,990,000 cubic feet. The principal dimensions compare as follows:—

Length, L.49, 634 feet; new ship, 584 feet.

Diameter, L.49, 78·7 feet; new ship, 83·5 feet.

It would appear that a decrease in the length-diameter ratio is of great advantage, and were it not for the necessity to consider the height of existing hangar doors, airships might well be made fatter than the German models.

ABSTRACT OF APPENDIX V.

The Model Basin.—Naval architects first came into aeronautics in connection with seaplanes. The aeroplane was developed before the seaplane, and at first the great problem was to design the boat or float so that the seaplane could actually leave the water. The early attempts were rarely successful, and it was not until a satisfactory form of planing bottom had been developed by model experiments in the towing basin that any consistent success was had. The contribution of the model basin to aeronautics is too well known to be gone into here. Existing methods and apparatus which had been developed for the study of the resistance of ships were immediately available as soon as it could be demonstrated that Froude's law of corresponding speeds applied to the planing action of flying boats. Such a verification was soon demonstrated by the successful performance of seaplanes designed from the results of model tank experiments.

It is now possible to test in the tank, at small expense and no risk, any proposed form of planing hull and to determine whether or not such a hull is worth constructing full scale. It is, therefore, possible to eliminate a great many types which would prove to be disappointments, and it is also possible to experiment with a great variety of minor modifications in form to determine the effect upon general behavior of these modifications. As a result of the last four years' work at the experimental model basin at the Washington Navy Yard by my colleagues, Commander Richardson and Commander McEntee, two forms have been developed which, for general purposes, we have found superior to the others. One is a pontoon which has been used on single and twin float seaplanes, and the other is a form of hull which was used for the N. C. flying boats. These forms

may not be the best known, as regards resistance or any other single feature, but have proved of all-round utility.

These forms are both what is called "vee bottom," and although this form of bottom behaves well in rough water and reduces the shock of landing, it is objectionable on account of the spray thrown out from the chine. For a twin float installation this is often a serious matter, as the spray gets in the propeller and causes trouble. A recent scheme to protect the propeller from spray has been suggested by Mr. Grover C. Loening. For twin float machines, he proposes floats with a bottom sloping outboard from the inner chine. This appears to eliminate all spray between the pontoons throwing it outboard. The experiments in the towing tank record all those things which can be measured, but do not record the spray and wave formation. We have recently undertaken the study of the wave formation which accompanies a planing boat by the use of an ultra-rapid motion picture camera, which takes pictures at eight times the rate of the commercial machine. When projected on a screen at ordinary speed (16 per second), this gives a view of the whole wave system to a microscopic time scale. This work is too new to warrant any conclusions from it, but I mention it as being a suggestive means of studying a very complex state of affairs.

An extension of the usual work of the model basin has led to the investigation of the strength of flying boat hulls to resist the shock of landing. For this purpose, accelerometers are mounted in the hull. Attempts to use the R.A.F. accelerometer were disappointing. This instrument had been used in the air for acrobatic flying with very satisfactory results, but it appears that the force at landing is too suddenly applied to be easily measured by this type of apparatus. Another type of accelerometer, developed by Dr. A. F. Zahm, has been used with very consistent results. This instrument depends only on the deflection of a series of light vertical springs by a series of masses and gives a definite maximum. With this instrument landings have been made in smooth water and it appears that the vertical component is seven times gravity and the horizontal component 2·5 times gravity. An R. A. F. instrument mounted alongside the Zahm instrument gave at the same time three times gravity and 1·7 times gravity, respectively. The large vertical components are noteworthy and appear consistent with our experience where engine foundations on flying boats and pontoon struts have failed, although they were designed for a load factor of eight.

Conclusion.—In this paper I have discussed in rapid succession five applications of naval architecture which could only be developed in detail in the appendices. Consequently, I cannot expect to have demonstrated more than the existence of these methods of attack and to have advertised their utility. It will be noted that two principal methods only have been used.

The first is the analysis of experience by means of a comparison of percentage weights, percentage control areas, &c., for a large number of successful aircraft. Similarly an analysis of experience is attempted in the comparison of metacentric heights. Normand's method of differentiating a weight equation is also based upon experience, and the method will not attain its maximum value until weight statements for a great many more airships are available. I cannot urge too strongly the general advantage to the art which would result from the full and frank publication of technical information regarding not only successful designs but failures as well. The failures in particular are priceless, but perhaps it is too much to expect of human nature that a *post mortem* on a bad design will see the light of day.

The second peculiarly naval architectural method used in aeronautics is model experimentation. A theory of similitude, geometrical, mechanical or dynamical, is used to apply model basin tests of boat hulls, wind tunnel experiments on aerofoils, and model propeller tests. Such a general use of similitude in design is unique in engineering practice and forms the closest bond between the naval architect and the aeronautical engineer.

The analysis of experience is really a statistical method for which trustworthy data in quantity are necessary. Given the necessary information, the naval architects' methods not only reveal the past and present state of the art as represented by engineering coefficients and averages but also show the trend of the more successful designs. In that way, future development and the most promising directions for improvement can be predicted. To avoid leaving the impression that the naval architect is looking backward exclusively, I should like to take the opportunity to recall the astonishing success of the little airship built by Dupuy de Lome in 1872. This eminent naval architect attained by his professional skill the maximum success which the state of the mechanical art at that time permitted. His little hand-propelled "Aerial Ship" exhibited all of the principal features of our modern non-rigids in their fundamental forms. Control and stability were correctly understood and provided for. An airspeed meter was also provided. The requirements of our modern theory of suspending a car below a non-rigid gas bag were met by his suspension system. A ballonnet and blower were used in accordance with good practice. More remarkable still, Dupuy de Lome made the envelope of two-ply rubberized fabric and doped it with a very fair gelatine, glycerin, acetic acid varnish to make it tight.

I quote from a contemporary account:—*

"The stability was something marvellous; several persons moving about in the car at the same time did not produce any oscillation. A descent was intentionally made from 1020 m. to 600 m. without making use of the ballonnet. The folds in the balloon then became very marked, and it was interesting to observe the tension of the various ropes as they maintained the major axis of the balloon in a horizontal position.

"The complete agreement of the results of the trial with those foretold by the inventor will be obvious to everyone. Such an agreement, usually so rare, is the more extraordinary as in this case all the bases of calculation had to be discovered.

"Henceforth aerial navigation may be said to possess a theory of stability and propulsion. The true history of ballooning will date from February 2, 1872, a new era marked by the invention of the navigable balloon, and rendered illustrious by the name of M. Dupuy de Lome, so well known in connection with scientific progress and invention."

The name of Dupuy de Lome deserves to be remembered not only as the leading naval architect of his day, but also as the first naval architect to apply his art to aeronautics.

In closing, I should like to express my appreciation of this opportunity to present before this society some of the later knowledge of the Navy Department in an effort to make at least a small return for the very valuable work which the Royal Aeronautical Society has done in publishing and distributing for the benefit of the art the best knowledge of British aeronautical engineers. My chief, Admiral D. W. Taylor, Chief Constructor of the Navy, especially welcomed this continuation and extension of the cordial relations established during the war, and authorized me

* Leclert, "Naval Science," April—October, 1872.

to disclose anything or everything of value in the possession of the Bureau of Construction and Repair. The Secretary of the Navy is much pleased that an officer of the United States Navy has been invited this year to read the Wilbur Wright Lecture, and desires me to express his gratification. The foundation of the Wilbur Wright Lecture is an institution very much to the credit of the Royal Aeronautical Society, which is not only the oldest aeronautical body in the world, but also the first to found a permanent memorial to my countryman. This early recognition of the Wrights by this society has ample justification, for this very Hall might not still exist tonight had not Wilbur and Orville Wright's invention been overhead to protect it. In honoring Wilbur Wright, we meet on a common ground. Firstly, relations between our countries will be furthered by transatlantic flying, and it seems very appropriate that the most intimate contact should be maintained by those technical and scientific workers who are striving for the same end: The improvement and application of the gift of flight left us by Wilbur Wright.—"Engineering."

THE AIRCRAFT DYNAMOMETER HUB.*

In this article it is proposed to deal with the details of construction of a dynamometer hub as used at the present time. This device is fitted on to the extention of the crankshaft instead of the usual propeller hub, and carries the propeller in such a way that the propeller is in the same position as with the usual method of fitting. The dynamometer hub consists of gauges with automatic regulation fitted between the two main parts of the device, moving independently one of the other; one of these is connected to the crankshaft and the other is connected solid to the propeller. These gauges are the most suitable of any type of dynamometer for the required purpose owing to the following three reasons:

1. There is no lost motion in the gauges. The gauging devices and parts transmitting the forces are not displaced relatively to one another with varying loads.
2. No spontaneous oscillations occur.
3. The method of construction damps out the forced oscillations (generated especially by the crankshaft and propeller).

These advantages are of greatest importance, as in this method the heavily oscillating forces generated by the engine act on the dynamometer hub without being balanced by any flywheel mass and measurements in these circumstances are only rendered possible by those advantages.

The automatically regulated gauge invented by Professor Dr. Bendemann‡ is illustrated in Fig. 1 in its most usual form. It consists of a cylinder *a* closed at one end, in which is a light piston *b* which must be a good oiltight fit in the cylinder. External forces are transmitted to the piston through a tappet *c*. An oscillating lever *d* is fitted on the top of the cylinder. This lever passes between two collars on the tappet, and each end is connected to the regulating pistons *e* and *f*, fitted into holes bored through the cylinder. When a load impresses itself on the tappet, the piston is depressed. The regulating piston *f* then allows a fluid under pressure to flow into the cylinder from *g* until the piston *b* is forced up again.

The movement of the piston causes the regulating piston *f* to reduce the

* Extract from the 18th Report of the "Deutschen Versuchsanstalt für Luftfahrt," issued in Technical Memorandum No. 19, by the Controller of Information, Department of Controller-General of Civil Aviation, Air Ministry.

‡ German patent 275,983, cf. T.B., vol. i, No. 1, page 61.

passage for the fluid gradually, until the piston has resumed the position illustrated, when the passage is completely closed by the regulating piston. The pressure under the piston is then proportional to the load acting on the piston (if the friction on the piston is not taken into consideration) and can be gauged by means of a manometer fitted at *h*. The same process occurs when there is a loss of compressed fluid through leakage. As the load acting on the piston decreases, the compressed fluid flows back under the piston through *h*. (All manometers in use act on the principle of change of volume.) The piston rises and the regulating piston *e* allows the fluid to flow out freely until the initial position is reached.

If sudden alterations of the load acting on the piston are not taken into consideration, the stroke of the piston is very small, it being determined by the position of the regulating pistons and the transmission of the lever. It is possible so to reduce the stroke as to render the movement negligible. The piston then remains constantly in the working position of the gauge. If two or more gauges are required to measure the same force together, only one regulating piston is required, the compression chambers being all connected.

The advantages of this device as mentioned above—freedom from oscillations and damping-out action—reach a maximum when the regulation of the outward flow is discarded (by which an economy of oil is also effected) and when compressed oil free from air is used. Machine oil absorbs a large quantity of air when subjected to compression. The lowest quantities found by tests carried out at a temperature of 20 degrees C. are given in the following table:—

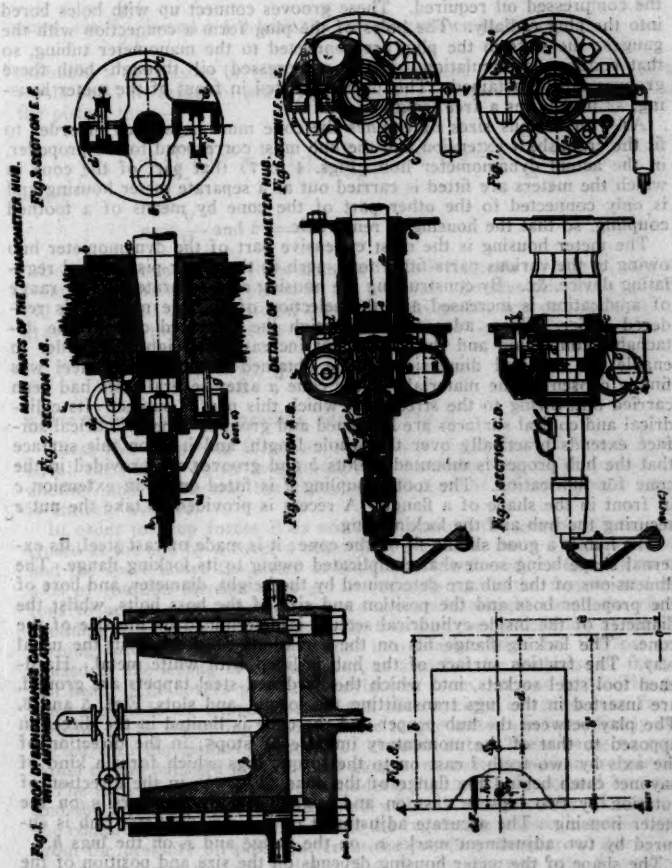
TABLE I.

Compression	1	2	3	4	5	6	12	20	27	31 atm.
Air obtained in percentage of volume at 1 atm.	30	40	48	52	55	56	59	64	69	70 p.c.

These figures show that the compression must not be produced by means of compressed air but by means of a pump, and that no air must be allowed to come into contact with the oil whilst it is under pressure.

The main parts of the dynamometer hubs, Figs. 2 and 3, are the cone, the hub proper, the gauge housing, and the plug; to these must be added tubing, recording instruments, pressure oil pump, &c.

The cone piece *a* is keyed on to the crankshaft extension and secured by means of a nut. It is cylindrical in section along the part where the hub is usually fitted, and the hub proper *b*, which carries the propeller instead of the usual hub, fits freely round it. The mounting containing the gauges is fitted into the forward extension of the cone beyond the hub. In order to satisfy the need for symmetry there are two thrust meters and two torque meters. The axes of the thrust meters *c* lie parallel to the axis of rotation; the torque meters *d* are so fitted that their axes are tangential to a circle at right angles to the main axis, the center of which is on the axis of rotation; in this way the torque is transmitted to the meters directly. There are two lugs *e* on the hub *b*, which are opposite the torque meters when correctly located relatively to one another. Tappets *f* transmit the forces from the torque meter to these lugs, and the tappets *g* of the thrust meters also transmit the forces to the hub. A


MAIN PARTS OF THE DYNAMOMETER HUB.
Fig.1. PROF. DU BOIS REYMOND'S CAUSE, WITH ARTHUR'S MODIFICATION.
Fig.2. SECTION A.B.
Fig.3. SECTION E.F.
DETAILS OF DYNAMOMETER HUB.
Fig.4. SECTION A.B.
Fig.5. SECTION C.D.
Fig.6.
Fig.7.

connection between the revolving meters and a stationary pressure gauge and recording instrument is carried out by means of a so-called plug *h*, a comparatively long piston fitting exactly into a cylinder *i*. Holes are drilled lengthwise in the plug equidistant from one another and from the edge, the number of grooves varying with the number of connections for the compressed oil required. These grooves connect up with holes bored into the plug radially. The holes of the plug form a connection with the gauges; the slots in the plug are connected to the manometer tubing, so that continuous circulation of the compressed oil through both these grooves can be obtained. This device is fitted in front of the meter housing, as it requires a free length of shaft.

As with various sizes of engines the cone must be altered in order to fit the crankshaft extension and the hub must correspond to the propeller, in the actual dynamometer hub (Figs. 4 to 7) that part of the cone in which the meters are fitted is carried out as a separate meter housing and is only connected to the other part of the cone by means of a toothed coupling, so that the housing is removable.

The meter housing is the most expensive part of the dynamometer hub owing to the various parts fitted to it, such as the meter pistons and regulating device, &c. By constructing the housing as a separate part its range of application is increased and the selection of suitable material is rendered easier. These advantages outweigh the increased cost of the detachable connection and the consequent increase in weight. In order to enable the required dimensions to be obtained chrome-nickel steel was finally chosen as the material for the cone *a* after several tests had been carried out, owing to the stresses to which this part is subject. Its cylindrical and conical surfaces are hardened and ground. The cylindrical surface extends practically over the whole length, and it is on this surface that the hub proper is mounted. Slots *b* and grooves are provided in the cone for lubrication. The tooth coupling *d* is fitted on to an extension *c* in front in the shape of a flange. A recess is provided to take the nut *e* securing the hub and the locking ring.

The hub is a good sliding fit on the cone; it is made of cast steel, its external shape being somewhat complicated owing to its locking flange. The dimensions of the hub are determined by the height, diameter, and bore of the propeller boss and the position and size of the boss bolts, whilst the diameter of the inside cylindrical section is determined by the size of the cone. The locking flange fits on the serrations of the hub in the usual way. The friction surface of the hub is lined with white metal. Hardened tool steel sockets, into which the hardened steel tappets are ground, are inserted in the lugs transmitting the torque, and slots, Figs. 5 and 6. The play between the hub proper and the cone is limited in the direction opposed to that of the momentary impulse by stops; in the direction of the axis by two teeth *l* cast on to the torque lugs which form a kind of bayonet catch behind the flange of the cone (Fig. 6); in the direction of rotation by two lugs *m* cast on and engaging with two bars *n* on the meter housing. The accurate adjustment of the dynamometer hub is ensured by two adjustment marks s_1, on the flange and s_2 on the lugs *h*.

The shape of the meter housing depends on the size and position of the torque-meter pistons. They must not only be exactly opposite the corresponding tappet sockets, but they must also be so placed that the centrifugal forces of the pistons and oil do not influence the measurements. For instance, should a piston with a plane head, the radius of which is *r* and the area F, rotating about an axis O (Fig. 8), with an angular velocity ω, be under the influence of a column of liquid reaching to the axis of

rotation the specific weight of which is γ_1, this column of liquid applies to the piston a force—

$$P = c.\ F.\ \left[a^2 + b^2 + \left(\frac{r}{2}\right)^2\right]$$

when $c = \frac{\omega^2 . \gamma_1}{2g}$ and $a + b$ have the meaning shown in Fig. 8.

Should a depression be made in the piston head the capacity of which would be V, its center of gravity S_v being at a distance s from the head of the piston, then—

$$P = c\left[F\,(a^2 + b'^2) + \left(\frac{r}{2}\right)^2 + V\,(2s - u)\right],$$

where

$$u = \frac{V}{F} \text{ and } b' = b - u$$

Both these expressions show that the force P depends on b or b', that is, from the position of the piston in the cylinder. Besides this force, a partial force Z_d of the centrifugal force Z of the piston acts on the center of gravity S_k of the piston (the weight of which is G_k), so that we have

$$Z_d = G_k . \frac{\omega^2}{g} . d = G_k . \frac{\omega^2}{g} . (b - e),$$

where d and e have the meaning shown in Fig. 8.

These two disturbing forces act in opposite directions. If P and Z_d are equal, then b can be so determined that the disturbing forces cancel one another, and in this way the disturbing influence of the centrifugal forces is entirely avoided.

In order to keep forces P as small as possible, the gauge cylinders are closed at the end by a cover o secured by a circular nut p (Figs. 5 and 6), and the space under the piston is filled with oil, the oil penetrating to the axis of rotation through slots q. In order to enable the tappets and pistons to act on each other the covers are made oiltight round the corresponding extensions of the piston. In this way the cancellation of the disturbing forces P and Z_d only comes into consideration for the lost area caused by the letting in of the cover, as also for the thickness of the piston head. The covers protect the cylinders from dirt and grit. The pistons are made of tempered steel and their weight is reduced as far as possible. The regulating pistons of the torque meter are immediately connected with the pistons by means of circular nuts. There being no regulation of the outward flow in these gauges, no control rods are required.

The ends of the thrust-meter cylinders, Fig. 5, are also closed by covers and the intermediate spaces are filled with oil. It is worthy of note that the compressed oil delivered through the regulating pistons is not obtained from the pressure oil pipes but from the pressure chamber of the adjoining torque meter through a slot r (Fig. 6). In this way both the gauging systems are connected in sequence, this being rendered possible by the fact that the gauging pressure in the thrust meters is constantly lower than in the torque meters.

The gauge housing can only be produced by casting owing to its complicated external shape necessitated by the arrangement of the meters. Grey iron was chosen for the construction of the housing, as copper alloys

were out of the question owing to the urgent necessity of economy in these metals and if cast steel had been chosen special bushes for the pistons would have been necessary. In the center of the housing is an annular body with the teeth of the coupling at the rear end and the fitting for the plug in front. The two cylinders of the torque meters are fitted on the annular part and are strengthened by means of central ribs. In this way a T-shape is given to the critical cross-section for the force to be transmitted by the gauge, and is stressed in such a way that the material most liable to failure under tension is also compressed.

In the case of the thrust meters the cylinders are so fitted on the central ribs that these form the bottoms of the thrust meter cylinders. Here also sufficient strength of the cross-section required to take up the forces is obtained by means of ribs. Rods n are provided on the cylinders of the torque meters to act as stops for the lugs m on the nose-piece. These stops come into operation when the torque becomes negative or it is required to disconnect the dynamometer hub when oil is being fed into the torque meter for the regulation. The pressure oil tube is connected at t_1, the gauging tubes at t_2 and t_3, whilst the torque meters are connected together at t_4 and t_5 and the thrust meters at t_6 and t_7. The meter housing is secured to the cone by means of an end plate provided on the annular part of the housing, the shaft of the hollow securing screw v being passed through the opening in the plate and screwed into the nut e of the hub. The head of the screw, provided with a locking ring w, then comes in contact with the end plate, securing the housing and also taking up the thrust of the propeller. The pitch of the thread of the hub nut is always higher than that of the crankshaft.

The plug is made of phosphor bronze and is screwed on to the gauge housing by means of a flange and circular nut. At the same time it closes the inside of the housing filled with oil.

There are three grooves inside the plug which at t_8, t_9 and t_{10} connect with small tubes leading to the points of connection t_1, t_2 and t_3 on the housing. The stationary plug is made of tool steel: it is pierced with four slots, one of which goes through the whole length.

Copper tubes of 3 mm. inside diameter are fitted to the head of the plug, one of these being for the compressed oil, two transmitting the gauging pressure for the torque and thrust and the fourth tube being connected to the long slot. Oil is led through this tube to the inside of the gauge housing and from thence under the piston of the gauge or between the cone and hub proper. This supply of oil is regulated by means of a cock.

A safety rupturing device is fitted on to the head of the plug, which prevents any part of the dynamometer hub from getting out of order, or from coming into contact with the propeller, should the plug jam. For this purpose the copper tubes are led through a sheath mounted on ball bearings and along a lever attached to this sheath. A wire of a fixed breaking strength—70 to 80 kg.—is stretched between the sheath and lever. Under the usual working conditions this wire takes up the torque of the plug friction. Should this friction exceed a certain magnitude the wire breaks, and the tubes are cut off in the sheath and the sheath continues to revolve on the ball bearings with the plug.

The plug being a new part was carefully tested whilst in use for frictional resistance, reliability of transmission of pressure, and leakage. It was ascertained that the torque due to friction was from 0·1 kg. to 0·25 kg., the transmission of pressure was perfect, and under usual working conditions the loss of oil through leakage for each oil-tight surface

amounted to 25 cub. cm./hr. when 40 is the degree of fluidity of the oil (according to Engler). The total consumption of oil for the hub can be divided as follows:—

	Cub. Cm./Hr.
Thrust meters	60
Torque meters	100
Recording instrument	10
Plug	50
Tubing (about)	30
Total	250

The tubes are led to the recording stand from the lever on the plug. As a rule the tubes are carried round the propeller to the engine on a bracket made of thin walled tubing, and from thence to the recording stand. All the accessories required for the dynamometer hub-pump, air chamber, oil tank, oil distribution system for regulation and lubrication, recording instruments are fitted in a small table, easily carried on the machine.

Tests with the Dynamometer Hub.—The dynamometer hub was first of all fitted to a propeller testing apparatus driven by an electric motor with oscillating frame. The friction of the oscillating frame amounts to about 0·5 kg., and is comparatively high for low performances. With increased performance the loss incurred through the increased oscillations from the increased number of revolutions is not only proportionally but actually smaller, and with a torque of from 60 kg. to 80 kg. the loss is so small that no influence can be detected by ordinary means. The electromotor can be regulated to a special torque by varying the field voltage. This requires some practice as the practically instable frame oscillates constantly.

The largest error in the measurement of thrust amounts to ± 5 kg. In order to calibrate the dynamometer hub, the torque was increased by 10 kg. from 30 kg. to 80 kg., the engine revolutions were regulated correspondingly, and the thrust was only gauged from 50 kg., as with a lower torque the inaccuracy is too great. The diagrams recorded during this calibration test are separated by about 34·5 mm., corresponding to the arrangement of the recording pencils. In order to curtail any unnecessary length of the chart, the recording mechanism was constantly stopped during adjustment.

According to this the error amounts on an average to about 0·5 per cent for the torque and 1·3 per cent for the thrust measurements. As there is no reason why the dynamometer hub should gauge the thrust less accurately than the torque, the greater inaccuracy in the thrust values must be ascribed to the low degree of sensibility of the thrust gauging device on the testing apparatus. The error in the torque measurements must be considered very small, even if it were solely due to the dynamometer hub, whereas the testing apparatus and the recording instrument are just as much sources of error as the dynamometer hub.

Later the dynamometer hub was mounted on an aero-engine test bench with oscillating frame. This system is not very suitable to calibration, but in this case the dynamometer hub was required to work on an aero-engine, that is, under the same conditions as on an aeroplane. In spite of the various parts being subjected to much higher stresses the dynamometer hub worked in the same way as on the testing apparatus. The engine

generates a torque of 80 kg., and the propeller thrust of 455 kg. The thrust varies slightly, the test bench being in the open near several others, so that wind and artificial eddies influence the propeller.

The dynamometer hub having given satisfactory results in this test, it was then mounted on an aeroplane and given a test run. It was then especially ascertained that no new vibrations of any importance occurred from the dynamometer fitting.

Knowledge Gained by Tests.—The dynamometer was subjected to the heaviest stresses on the engine test-bench. Considerable vibrations occurred which, however, did not influence the measurements, but which so shook the pipe connections between the plug slide and gauge housing and between the pairs of gauges that they broke after 20 minutes' to 60 minutes' run. The pipes were then partly strengthened in order to reduce the number of their spontaneous oscillations and partly connected together or soldered and well secured. No fault was found with the working of the cone or hub proper. Slight overheating of the plug and slide was noted. The safety rupturing device came into action once or twice as the plug fitted too closely. Each time it was successful in preventing any damage being done to the plug or slide, so that the plug could be removed by hand. Since then every plug undergoes torque tests before being fitted.

The diagram shows that with sudden variations of the load the thrust varies less quickly than the torque and increases more slowly. This is a consequence of the inertia of the mass of the propeller and of the hub proper, for the acceleration of which a part of the engine performance proportional to the inertia must be used. The time which elapses between the disturbance of an existing state of equilibrium by a variation of the torque and the recovery of equilibrium must be taken into consideration when drawing up the diagram. The moment of inertia of the rotating masses, *i.e.*, the propeller and hub proper, is used to determine this interval T_u as the torque is gauged between the hub proper and the cone. In the case of a 160-horsepower hub with an "Eta" propeller, it was found by the well-known pendulum method that $I = 0{\cdot}49$ kg. sec.^{2} As the moment of inertia of the revolving engine driving gear, including the connecting rod parts* is known to be about 0·008 kg./sec.^{2}, that is about 1·5 per cent of the moment of inertia of the propeller, the following calculation can also be applied to aero engines with a rigid hub.

In the case of propellers we can write with sufficient accuracy, $M_1 = m \cdot \omega_1^2$, where M_1 is the torque with angular velocity ω_1 and m the torque when the angular velocity equals 1 to be ascertained by tests. Should the torque increase to M_2, whereby the angular velocity can also be increased to ω_2, during the passage from ω_1 to ω_2, with an intermediate angular velocity ω and the corresponding torque M an extra torque is produced:

$$M_u = M_2 - M = m\ (\omega_2^2 - \omega^2).$$

Therefore the angular acceleration at this point becomes—

$$\frac{d\omega}{dt} = \frac{M_u}{J} = \frac{m}{J} \cdot \left(\omega_2^2 - \omega^2\right).$$

* Tolle, "Regelung der Kraftmaschinen" (Regulation of power engines), 2nd edition, page 115.

If we integrate between the limits ω_1 and ω'_2 we obtain the time of the interval,

$$T_u = \frac{J}{2m \cdot \omega_2} \int ln \frac{\omega_2 + \omega}{\omega_2 - \omega} \int \frac{\omega'_2}{\omega_1}$$

as a logarithmic function from whence we obtain $T_u = \infty$ when $\omega'_2 = \omega_2$.

In order to obtain a standard by which to judge of the process, a degree of approximation must be introduced

$$\varepsilon = \frac{\omega_2 - \omega'_2}{\omega_2}$$

which on no account must be lower than the degree of irregularity of the engine.

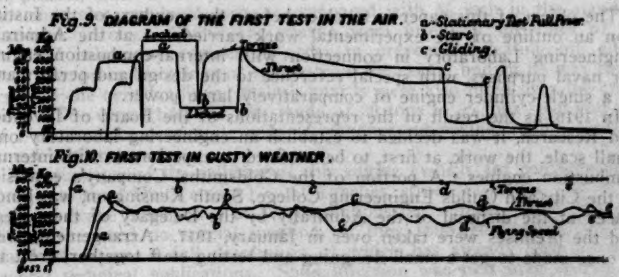
Further $\delta = \frac{\omega_2 - \omega_1}{\omega_2}$ is introduced as the relative alteration of angular velocity or of the number of revolutions, from whence

$$T_u = \frac{J \omega_2}{2 \cdot M_2} \cdot ln \frac{\delta (2 - \varepsilon)}{\varepsilon (2 - \delta)}$$

When $\varepsilon = 0.005$ and $\varepsilon = 0.001$, the following values are obtained :—

$\varepsilon = 0.005$	$\varepsilon = 0.001$
$\delta = 0.05, 0.1, 0.5, 1$	$\delta = 0.05, 0.1, 0.5, 1$
$T_u = 0.9, 1.2, 2, 2.5$ sec.	$T_u = 1.6, 1.9, 2.7, 3.2$ sec.

$\delta = 1$ corresponds to the starting time, $\varepsilon = 0.005$ is approximately the degree of irregularity of an aero-engine. When the value is decreased by 1/5 T_u is increased by approximately 0·7 sec., and *vice versa*. An accurate knowledge of the value corresponding to the degree of irregularity of the aero-engine is therefore not necessary.* The slower progress of the thrust forces, as compared to the torque, is caused by the values of T_u when they reach a magnitude of from 1 second to 3 seconds, as when the variations of the torque occur at regular intervals shorter than T_u at the same time, the thrust corresponding to the maximum angular velocity cannot be reached at all.



* For accurate determination, see Tolle's "Regelung," &c., and Kolsch, "Gleichgang und Massenkrafte bei Fahr- und Flugzeugmaschinen" (Regularity and forces of the masses in ship and aero-engines).

Flying Tests.—After these preliminary tests were completed, the first dynamometer was mounted on a Rumpler C. II machine for the carrying out of tests during flight.

In the case of the instrument used the slip of paper moved at a speed of 10 mm./sec., and the instrument was fitted with two pencils set 34·5 mm. apart, the range of each pencil being 30 mm.

The first flying test was carried out on November 7, 1916, in clear and calm weather. It lasted about 15 minutes, and a height of 800 m. was attained. The results are shown in Fig. 9, shortened to scale (with the exception of the stationary test). The whole of the torque curve resulted in a heavy line, as the pencil also recorded the torque impulses of the engine in part. Before the flight a short test run *a* was carried out with $n = 1{,}000$ revolutions per minute, and also at full throttle.

On the engine being throttled down at the start with the dynamometer hub "locked," the torque curve rose to the maximum height the instrument is capable of recording. On the dynamometer hub being switched on to the gauging position as the aeroplane left the ground, a rise in both curves at (*b*) was recorded. As the value of the thrust rose to its maximum, where it remained, the thrust curve rose, but fell to a fixed level as the speed was increased. Both values decreased with increasing altitude. On the engine being switched off as the machine went over into a gliding flight a sudden fall in the curves at (*c*) was recorded. When near the ground the throttle was opened out again, and then the engine cut out again. The result is clearly visible in the diagram. The diagram obtained from a flying test carried out on April 3, 1917, a gusty day, is reproduced in Fig. 10. In this case the speed of the aeroplane was also obtained by means of a pressure disc.* The diagram shows clearly the influence of the various gusts in the thrust, from which the importance of obtaining a record of the speed of the aeroplane can be realized.—"Engineering."

SOME EXPERIMENTAL WORK IN CONNECTION WITH DIESEL ENGINES.†

By Engineer-Commander C. J. HAWKES, R.N. (ret.) Member.

The object of this paper is to place before the members of the Institution an outline of the experimental work carried out at the Admiralty Engineering Laboratory in connection with internal-combustion engines for naval purposes, with special reference to the design and performance of a single-cylinder engine of comparatively large power.

In 1916, as the result of the representations of the Board of Invention and Research, it was decided to establish an engineering laboratory on a small scale, the work, at first, to be confined to experiments with internal-combustion engines. A portion of the Goldsmiths' Company's extension of the City and Guilds Engineering College, South Kensington, was kindly placed at the disposal of the Admiralty by the Delegacy of the college, and the premises were taken over in January, 1917. Arrangements were at once made to get a small designing and testing staff together, erect the

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* Hoff. New recording instruments for measurements of forces and ascertainment of tensile strength of bracing wires during flight. *Zeitschrift für Flugtechnik*, &c. 1914—pages 21, 149.

†Paper read before the Institution of Naval Architects, July 8, 1920.

necessary workshop, machines and design and obtain experimental plant and engines. Sir Dugald Clerk was appointed Director of Engineering Research, a position which he held until February, 1918.

The question of the material and design of pistons of submarine oil engines was referred to the Board of Invention by the engineer-in-chief of the Navy and the matter was first considered at a meeting of the Internal-Combustion Engines Sub-Committee on November 29, 1915. The author was secretary of this sub-committee. It was decided to construct a single-cylinder oil engine for experimental purposes, utilizing, so far as possible, the parts of a standard submarine engine, in order to save time and also to keep down the cost. The drawings of the piston, connecting rod, bedplate and other parts not of the standard design were made at the Board of Invention, and the engine was constructed and erected at the works of Messrs. Ruston and Hornsby, Lincoln. The engine was first run without load on July 17, 1916.

Several designs of pistons were considered by the sub-committee, including pistons of aluminium alloy in two pieces and also pistons having aluminium alloy heads and suitably lightened bronze or cast-iron skirts. Eventually it was decided to commence the experiments with a piston of aluminium alloy and, in order to keep down the weight of the piston, a comparatively low copper content was decided upon. It was uncertain whether this piston would stand up to its work for any length of time, especially having in view the composition of the aluminium alloy then being recommended for pistons of aircraft engines, but it is interesting to note that the original piston is still in use and it has been run for a considerable time at comparatively high speeds and high mean pressures.

The trunk piston was divided at the gudgeon-pin center and the two top-end bearings were carried between its upper and lower portions—the gudgeon pin, to facilitate dismantling, being at first made a driving fit into the eye of the connecting rod. This design followed a suggestion which was put forward some years before in connection with ordinary cast-iron pistons, with the object of obtaining a slightly greater gudgeon pin bearing surface. The top-end brasses, which were lined with white metal, were not adjustable. Lubrication was effected by forced feed from the crankshaft through the center of the connecting rod and thence through channels in the hollow gudgeon pin to the bearings. The bearings were held in position by steel end plates. Six cast-iron piston rings were fitted in addition to a scraper ring, but, with the object of reducing the possible wear of the piston grooves, the width of the working faces of the rings were made ¼ inch, as compared with ⅜ inch in the standard cast-iron pistons. Aluminium guards were fitted on the lines of the standard submarine engines in order to prevent lubricating oil, either from the top-end bearings or splash from the crank, finding its way to the walls of the cylinder liner. Splash guards were also fitted over the crank webs. The connecting rod was made of 30 tons to 35 tons steel and was of I-section—the connecting rods of standard submarine engines being of round section.

The diameter of the cylinder of this engine (which, for convenience, is known as the "Unit" engine) is 14½ inches, stroke 15 inches, and of 100 nominal brake horsepower at 380 revolutions per minute. Other parts of the engine need no special mention, as they followed Messrs. Vickers' standard design, a full description of which has already been given in several technical publications. Solid injection was first used in this engine, but, later, air injection was fitted for experiments with a modified type of air-injection valve.

After the engine had been running at the full nominal load for some considerable time it was opened up for examination. It was found that the gudgeon pin was slightly slack in the connecting rod and it was decided, therefore, to modify the skirt portion of the piston so that it would pass over the foot of the rod for dismantling and thus permit a "shrunk in" gudgeon pin to be fitted.

When these modifications had been carried out the engine was transferred from Lincoln to the Admiralty Engineering Laboratory and the trials were continued in September, 1917. The engine was run at or above 100 brake horsepower at revolutions from 380 to 500 per minute and at mean pressures from 100 pounds to 140 pounds per square inch, and it was not opened out for examination again until July, 1918. It was then found that the piston was in good condition but the white metal of the gudgeon brasses had worn slightly. It appeared evident that this wear was largely due to the fact that the oil grooves had not been cut exactly in accordance with the instructions on the drawing, and this resulted in reducing the supply of lubricant to the grooves. It was also found that the brasses had hammered very slightly into the aluminium body of the piston and there was evidence that the side clearances between the connecting rod and the brasses were insufficient.

It was decided to bore the eyes of the piston larger, make new brasses of correspondingly greater thickness, with flanges at each end, and to fit more substantial keys to prevent the brasses turning in the piston—as the small keys originally fitted were found to be slack. The experiments have been continued since August, 1918, at mean indicated pressures up to 140 pounds per square inch, but it has not been necessary to make any further modifications to the piston. Whenever the piston has been dismantled it has been found in good condition, and careful gauging has shown that there is no appreciable wear either in the body of the piston or in the grooves—and, so far, there is no indication of "growth." The cast-iron cylinder liner is in excellent condition.

The weights of the aluminium alloy piston and I-section connecting rod of the experimental engine are appreciably less than the weights of the corresponding parts of the standard submarine engine, with the result that the inertia forces in the former at 500 revolutions per minute are approximately the same as in the latter when running at 380 revolutions per minute. The comparative weights of the reciprocating and rotating parts of the experimental cylinder and the standard engines are shown in Table I.

With the particulars given in the following Table the mean pressures on the various bearings throughout the cycle, at 380 revolutions per minute, were obtained for each engine and the results are shown in Table II.

It will be seen, as would be expected, that there is a considerable reduction in the mean total loadings of the bearings due to the use of the aluminium alloy piston and lighter connecting rod and, as the mean rubbing velocities of the various bearings are the same for both engines at 380 revolutions per minute, this reduction is a measure of the increase in the mechanical efficiency of the experimental engine as compared with the mechanical efficiency of the standard engine. This increase in mechanical efficiency would appear to be of the order of 2 per cent.

The coefficient of linear expansion and the thermal conductivity are greater for aluminium than for cast-iron and, in the absence of information so far as large engines were concerned, it was difficult in the design stage to decide on the clearances which should be provided between the aluminium alloy piston and the liner. It was essential that the clearances

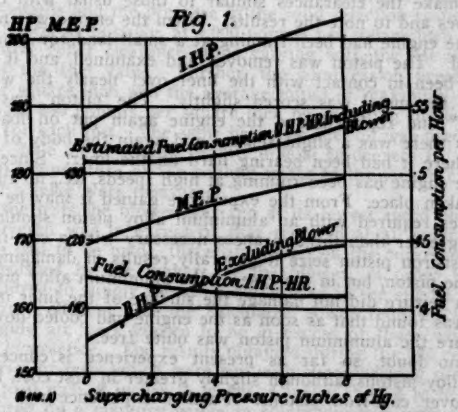


TABLE I.—*Comparison of Weights of Pistons and Connecting Rods in Experimental and Standard Submarine Engines.*

	Experimental Engine.	Standard Submarine Engine.
	in.	in.
Cylinder diameter	14¼	14¼
Length of stroke	15	15
Revolutions per minute	380	380
Weight of piston, with rings, bushes (in the case of experimental engine), guards, &c.	lb. 213	lb. 390
Weight of connecting rod, with gudgeon pin and large end bearing and bushes (in the case of standard engine)	290	423
Reciprocating weights (includes two-thirds weight of connecting rod without palm end)	310	560
Rotating weights (includes palm end and one-third weight of connecting rod)	193	253

TABLE II.—*Mean Total Bearing Pressures throughout Cycle in Pounds.*

Engine.	Gudgeon Pin.	Crank Pin.	Cylinder Liner.	Main Bearings.
Experimental engine	12,320	16,200	1,420	16,200
Standard engine	15,250	20,260	1,840	20,260

should not be greater than were actually necessary, and eventually it was decided to make the clearances similar to those usual with cast-iron in Diesel engines and to note the results. When the engine was first started, and after the engine had been running at a small load for some time, the piston seized. The piston was removed and examined, and it was found that it had been in contact with the liner over nearly the whole of its surface and the metal was scored slightly. The piston was therefore "draw filed" and replaced, and the engine again put on load. At the higher loads there was a slight seizure and again the body of the piston was filed where it had been bearing hard on the liner. Since that time, although the engine has been running at high speeds, &c., no further seizures have taken place. From the experience gained it may be taken that the clearances required with an aluminium alloy piston should be about 50 per cent greater than the clearances necessary with a cast-iron piston. Should a cast-iron piston seize it generally results in damaging the liner as well as the piston, but in the case of the aluminium alloy piston it was found that a seizure did not damage the surface of the liner in any way. Further, it was found that as soon as the engine had cooled down slightly after a seizure the aluminium piston was quite free.

There is no doubt, so far as present experience is concerned, that aluminium alloy pistons, although slightly greater in first cost, have many advantages over cast-iron pistons. Further experience will shortly be avialable as to their behavior under actual service conditions and it will then be possible to decide whether their extended use for submarines is justified. In the meantime other Admiralty experimental engines, including the two-stroke cycle type, have been or are to be fitted with pistons of aluminium alloy for further test.

In view of the results obtained with the "Unit" engine it was decided, when the engine had been transferred from Lincoln to the Admiralty Engineering Laboratory, further to test the capacity of the piston to withstand higher mean pressures by supercharging and also to run at higher speeds. The two methods of supercharging considered were (1) to compress to the supercharging pressures the whole of the air required by the engine by means of a blower or pump, the air passing through the induction valve, or (2) to allow the engine to draw air from the atmosphere through the induction valve in the ordinary way and to add at or about the commencement of compression the additional air for supercharging through ports uncovered by the piston or through an additional valve in or near the cylinder head. The alternatives were fully considered, but as the principal object at that time was to test the aluminium alloy piston it was decided to adopt (1) as it did not involve any structural alterations to the engine. It was consequently arranged to compress to the supercharging pressure the whole of the air required by the engine by means of a standard Roots blower, driven by belt from an electric motor. The blower delivered air under pressure to a reservoir, which was fitted with a combined relief and pressure regulating valve, so that the supercharging air could be adjusted to any predetermined pressure within the capacity of the blower. A three-way cock was fitted in the induction pipe so that the engine could take its supply of air either from the atmosphere or from the reservoir. This arrangement gave no trouble, but it was found that the temperature of the air delivered at 3 pounds or 4 pounds pressure after a time rose appreciably and a water-jacket was therefore fitted to the blower.

Tests were then carried out with and without supercharging at various speeds up to 500 revolutions per minute, using the maximum quantity of

fuel oil delivered by the fuel pump. A six-hole sprayer was necessary at the higher speeds and the pressure in the solid injection system was maintained, as nearly as possible, at 4,000 pounds per square inch by adjusting the fuel valve roller clearance—thus varying both the lift and period of opening of the fuel valve. Further, the compression pressure was 380 pounds per square inch and the average initial or maximum pressure was kept at about 630 pounds per square inch by adjusting the timing gear as necessary for each test. The same brand of fuel oil was used throughout, viz., heavy shale oil of specific gravity 0·86 at 60 degrees F. The quantity and rise in temperature of the cooling water to the jacket, cylinder cover and exhaust valve were measured.

During the tests the blower was run at its lowest speed but the amount of air delivered was in excess of that required at all engine speeds. A calculation had to be made, therefore, based on the curves of output and power furnished by the makers of the blower, in order to obtain the power required to supply the air actually used in the engine. The blower was not very efficient and the calculated power required to supply the supercharging air were known to be in excess of those which would be necessary in practice. The results obtained during the 500 revolutions per minute series of tests which were run with supercharging pressures corresponding to 0 inch, 2 inches, 4 inches, 6 inches, and 8 inches of mercury (as measured by a mercury gauge in communication with the reservoir) are shown graphically in Fig. 1. The fuel consumption per brake horse-power hour inclusive of the blower are estimated. Each trial was of 1½ hours' duration.

Although the powers developed during the tests were limited by the capacity of the fuel pump, the results obtained could not be regarded as satisfactory. The exhaust was not clear during any test and it was evident that it was necessary either to make some alteration to the fuel sprayer or to adopt a different system of fuel injection. It was therefore decided that no good purpose would be served by continuing these tests and it was consequently arranged to experiment with the fuel-injection system and to defer the supercharging tests until a later date.

Better results, both as regards power and fuel consumption, would have been obtained by running these tests at higher initial pressures, but it was desirable, at least for the present, to limit the maximum pressure to that usually worked to on service. The results could also have been improved by using a higher fuel pressure in the solid injection system but, again, it was considered advisable at that stage, and with the fittings then in use, to limit the pressure to 4,000 pounds per square inch. During the later tests diagrams were taken from the fuel system with the object of ascertaining the variation of pressure during the cycle. For this purpose an ordinary hydraulic indicator was used, but as the fuel oil was found to leak, past the piston a U-pipe connection was made to the indicator and filled with heavy oil—so that the heavy oil was in contact with the piston. This overcame the difficulty and it is considered that reliable records of the variation in pressure were obtained. It was found that with a gauge pressure of 4,000 pounds per square inch in the fuel system, with the engine running at 420 revolutions per minute, the maximum pressure was 4,560 pounds and the minimum pressure 3,400 pounds per square inch.

The exhaust pipe outlet to the atmosphere is some considerable distance from the engine and for convenience it has been arranged to spray water into the first of the two silencers fitted and to note the color of the discharge from the silencer drain by passing it over a plate of glass painted white on its inner side. It has been found that this method is

very sensitive and can always be relied upon to give a true indication of the color of the exhaust. This method has also been used successfully for other experimental engines.

The indicator-rig originally fitted to this engine was considered to be unsatisfactory and a new gear was fitted, an arrangement of which is shown in Fig. 2. It will be seen that a steel tape, 0·006 inch in thick-

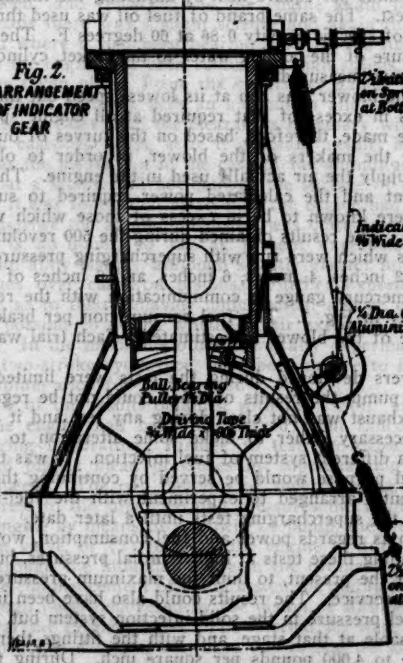

½ Initial Stretch on Spring with Piston at Bottom of Stroke
Indicator Tape ¾ Wide x .004 Thick.
⅛ Dia. Cord. Aluminium Pulley
Ball Bearing Pulley 1½ Dia.
Driving Tape ¾ Wide x .006 Thick
½ Initial Stretch on Spring with Piston at Bottom of Stroke

Fig. 2.
ARRANGEMENT OF INDICATOR GEAR

ness, has one end connected to the piston and the other end connected to the rim of an aluminum wheel, which is mounted on a small shaft carried in a bracket attached to the engine framing. This tape passes over a ball-bearing pulley 1½ inches in diameter. The shaft carrying the aluminium wheel also carries the pulleys to which the tension springs are connected and the pulley from which the indicator tape is taken. By this means a true copy of the movement of the piston can be obtained. Some difficulties were experienced in connection with the tension springs and the tape fastenings but by running the whole of the gear in the open by an electric motor, so that all parts were under observation, these difficulties were readily overcome. Various minor alterations were made later, but the principle of the gear has remained the same. A photograph of the gear attached to the "Unit" engine is shown in Fig. 3. Since that time a large number of strands of rubber have been successfully used in place of the tension springs.

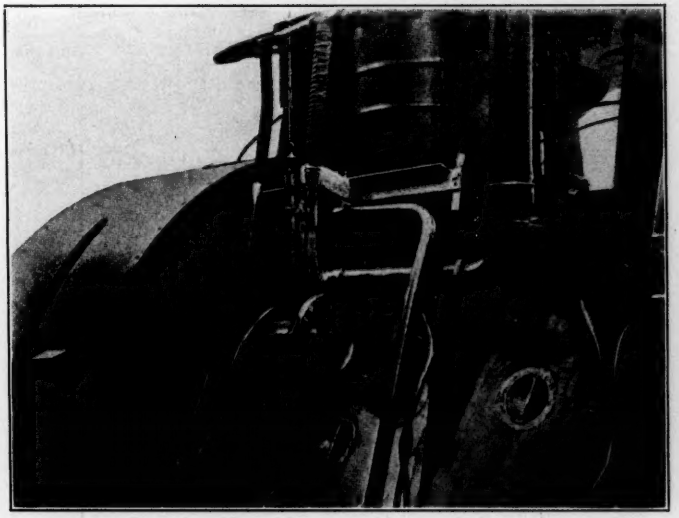


FIG. 3.

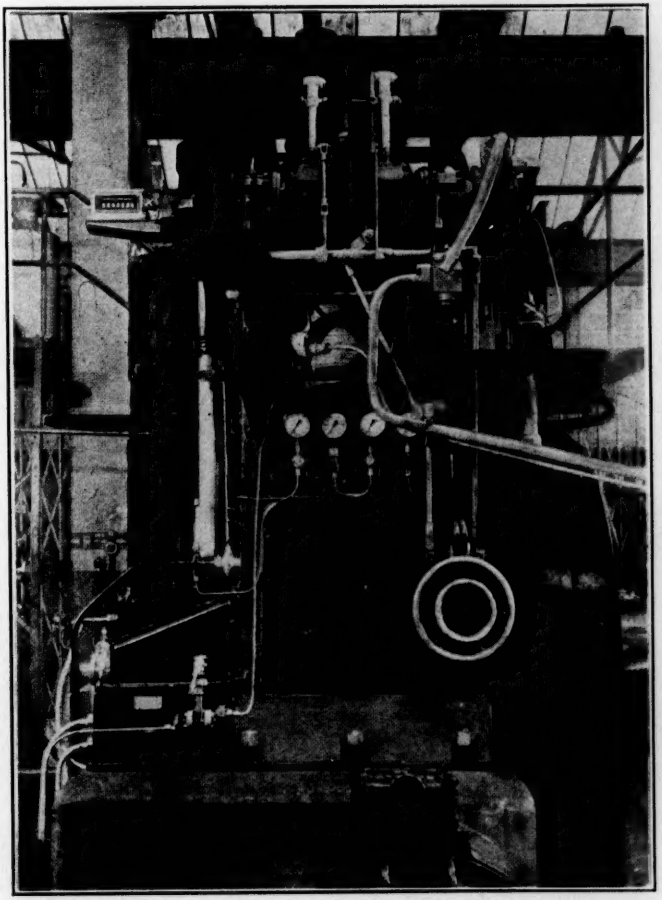


FIG. 5.—EXPERIMENTAL DIESEL ENGINE CONSTRUCTED AT CHATHAM DOCKYARD.

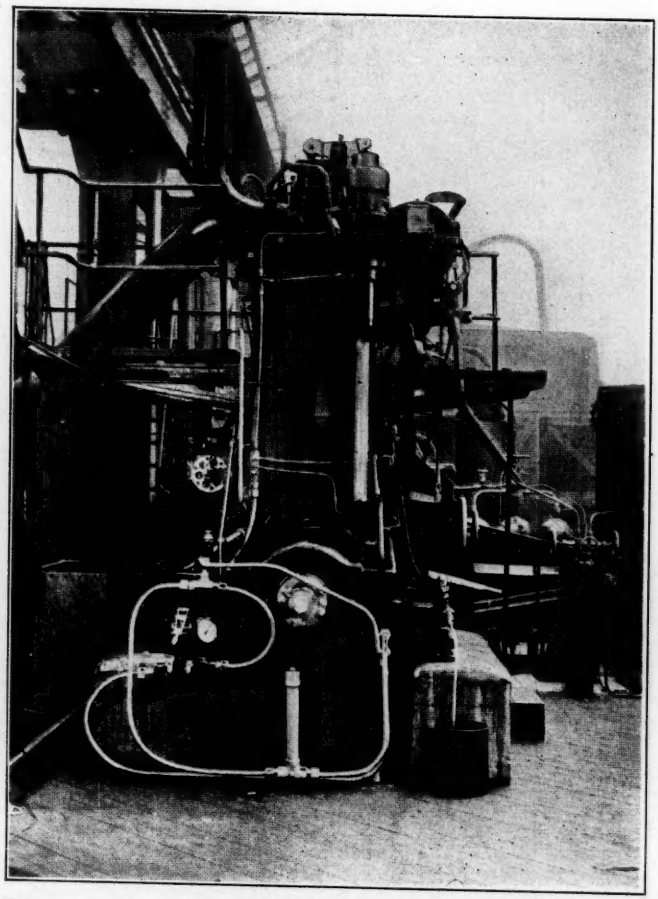


FIG. 6.—EXPERIMENTAL DIESEL ENGINE CONSTRUCTED AT CHATHAM DOCKYARD.

It may be interesting to mention, in connection with the "Unit" engine, that an obturator ring has been fitted to the piston since August, 1918, and has given fairly satisfactory results. The use of the obturator ring for Diesel engines was brought to notice by Messrs. The Engineering and Arc Lamps, Limited, of St. Albans, as a number of experiments had already been carried out in an engine at the St. Albans Electric Power Station, and very promising results obtained. The top of the cylinder liner of the power station engine was worn to the extent of nearly ⅛ inch on the diameter and the life of the phosphor bronze obturator ring under these severe conditions was about 800 hours. The general condition of the liner, however, was such that the ordinary type of cast-iron ring could not be used and the fitting of the obturator ring, although its life was comparatively short, certainly enabled the engine to be run.

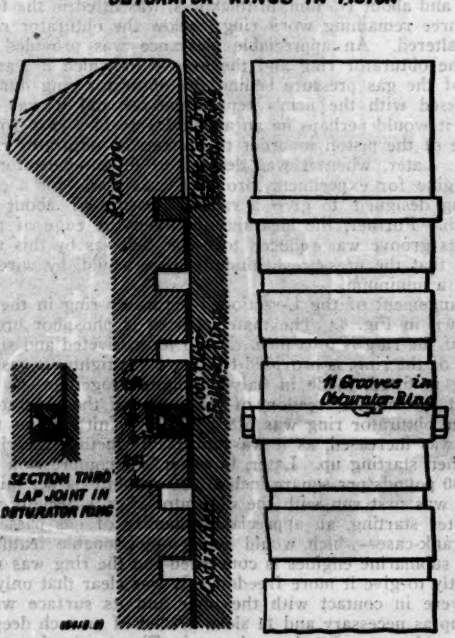
In the St. Albans engine the first three cast-iron piston rings were "pegged in" for the purpose of filling the grooves, an obturator ring of L-section, and about 1·5 mm. in thickness, was fitted in the fourth groove, and the three remaining worn rings, below the obturator ring, were retained unaltered. An appreciable clearance was provided between the edge of the obturator ring and the groove in which it was fitted. The question of the gas pressure behind the obturator ring during the cycle was discussed with the firm's representatives and it was suggested to them that it would perhaps be an advantage to fit a cast-iron ring in the top groove of the piston in order to protect the obturator ring from the hot gases. Later, when it was decided to fit an obturator ring to the "Unit" engine for experiment, provision was made for a cast-iron protection ring designed to give a radial pressure of about 1 pound per square inch. Further, the clearance between the edge of the obturator ring and its groove was reduced to 0·002 inch—as by this means it was considered that the pressure behind the ring would, by wire-drawing, be reduced to a minimum.

The arrangement of the L-sectioned obturator ring in the "Unit" piston is shown in Fig. 4. The material used is phosphor bronze and the thickness of the ring is 0·05 inch. A lap joint, riveted and silver soldered to one end of the ring, is provided to ensure gas tightness past the gap. A filling ring is fitted, made in halves spigoted together—its width being such that it just allows freedom of movement of the obturator ring.

When the obturator ring was fitted to the "Unit" engine the compression ratio was increased, as it was uncertain whether the ring would be gastight when starting up. Later, however, the compression was reduced again to 380 pounds per square inch at 380 revolutions per minute. When the engine was first run with the obturator ring, especially for about 15 minutes after starting, an appreciable quantity of gas passed the piston into the crank-case—which would be an objectionable feature so far as its use for submarine engines is concerned—so the ring was removed and eased slightly to give it more freedom. It was clear that only portions of the ring were in contact with the liner and its surface was therefore smoothed up as necessary and 11 slots, 1/32nd of an inch deep and 1/16th of an inch wide, were fitted, as shown in Fig. 4. At the same time the clearance between the edge of the ring and the piston groove was increased from 0·002 inch to 0·003 inch. These slight modifications resulted in a distinct improvement and the ring worked satisfactorily with mean indicated pressures up to 140 pounds per square inch. No leakage was apparent although the maximum compression pressure was very slightly less than that previously obtained with the full number of cast-iron rings with the same compression ratio in use. There was a very decided knock

in the piston at the end of the compression stroke and after running for a total of about 30 hours it was decided to examine the piston and obturator ring. The obturator ring was found to be quite free and bearing generally and there was no measurable wear. The ring was therefore replaced and, in view of the previous knocking of the piston, two additional light cast-iron rings were fitted below the obturator ring. These additional rings, which were intended to act as "buffer" rings, practically cured the knocking, but they must add slightly to the piston friction of the engine. It is probable that this knocking could have been avoided by reducing the piston clearance, but nothing could, of course, be done with the existing piston; neither was it desirable in view of running the engine at comparatively high mean pressures.

Fig. 4. UNIT ENGINE. ARRANGEMENT OF OBTURATOR RINGS IN PISTON



After running for about 150 hours at various powers the obturator ring was again measured and the wear appeared to be about 0·001 inch, whilst the maximum wear in the groove of the piston when gauged was found to be 0·008 inch. So far the obturator ring is promising, but it has been tested under very favorable conditions, and further experience is necessary before any recommendations could be made in regard to its general use in service engines. The original ring is still fitted in the engine, but

there has been no opportunity to ascertain the actual reduction in piston friction resulting from its use. There is no doubt, however, that the engine is more free than formerly and its mechanical efficiency has been slightly increased. It is not known whether any experiments have been made to ascertain whether obturator rings would work satisfactorily when running over ports, such as those fitted in two-stroke cycle engines, but it is probable that this will be tried at the laboratory at a later date.

Very good results have been obtained with the "Unit" engine both with the solid and with the air injection systems. Instructions were received to carry out experiments with the object of reducing the tendency of the standard engines to smoke when using solid injection. A large number of tests were made, which cannot be referred to in detail here, and eventually smokeless combustion was obtained with the "Unit" engine at all powers from 100 brake horsepower to 25 brake horsepower, and the consumption of fuel oil at 100 brake horsepower and 380 revolutions per minute was just under 0·4 pound per brake horsepower hour. Having in view the fact that the tests were carried out with a single-cylinder engine, fitted with a camshaft driving mechanism designed for a multi-cylinder engine, this figure for consumption is remarkably good. The fuel used was shale oil having a specific gravity of 0·86 at 60 degrees F. During all these tests the fuel oil was very carefully measured, and it may be mentioned that during a 6 hours' continuous test the variation in the consumption, recorded half hourly, was under 1 per cent. The "Unit" engine is coupled to a standard Heenan and Froude dynamometer for absorbing the power.

Tests were made with the above engine when using air injection and the fuel consumption at 100 brake horsepower, after making the necessary allowance for the power required to drive the air compressor, was practically the same as the fuel consumption when using solid injection.

Early in 1918, several British firms were asked to produce designs of single-cylinder experimental engines of from 300 brake horsepower to 400 brake horsepower, and one of these engines is now approaching completion. At about the same time a preliminary design for an experimental four-stroke single-cylinder engine of about 300 brake horsepower was prepared by the Admiralty Engineering Laboratory and instructions were received to proceed with the working drawings on May 1, 1918. Photographs of the engine, which was constructed at Chatham, are shown in Figs. 5 and 6. Owing to space requirements it was eventually decided to design a square engine, 20 inches diameter by 20 inches stroke, developing its full power at 390 revolutions per minute. The piston speed aimed at was, therefore, 1,300 feet per minute—which was an advance on previous practice. Although all the drawings were completed before any information was available as to the German designs it is interesting to note that the principal dimensions of the laboratory engine correspond closely with the dimensions of the German engines—the cylinder diameter of the latter being 20·8 inches, stroke 20·8 inches, and developing approximately 300 brake horsepower at 380 revolutions per minute.

The first point considered during the preliminary design stage, after fixing the cylinder diameter, &c., was the type of framing to be adopted. After full consideration of the various types it was decided, having in view stiffness of structure as well as weight, to adopt the steel column principle—the casting being of box form as shown in Figs. 5 and 6. For a multi-cylinder engine this framing should prove both rigid and comparatively light. Although it was intended that the framing for a multi-cylinder engine should be of cast steel it was decided, in order to get

quick delivery and to keep down the cost, to make the framing of the single cylinder of cast-iron—the scantlings being slightly increased over those necessary with steel. It may be mentioned that, with the exception of the moving parts, cylinder cover, fuel valve and a few minor fittings, parts which were intended to be made of aluminum or cast steel in a complete engine were in this instance made of cast-iron.

A water-cooled cast-steel sandwich plate, carrying the liner, is secured to the top of the column and the cast-steel cylinder head is in turn fitted to the sandwich plate—the studs for securing the head passing through the sandwich plate to the column. The liner now in use is made of close-grained cast-iron, but liners of special steel will be fitted for experiment later. At the lower end of the liner the water joint with the thin sheet steel water jacket is made by rubber rings in the usual way. The upper part of the water jacket is housed in the sandwich plate in such a manner that the pitch of the cover studs is reduced to a minimum. The bedplate is of cast-iron arranged for convenience to embody the lubricating oil pump. The lubricating oil pump, driven by an eccentric on an extension of the crankshaft and housed within the crank chamber, is of the Brotherhood valveless type.

The crankshaft is of ordinary 30-tons to 35-tons steel, and is fitted with cast-steel balance weights, lead filled. The connecting rod is of I-section, of 30 tons to 35 tons steel, with the corners of the palm end cut away, and to suit the piston-cooling gear the length between centers was made 4·9 cranks. The large-end bearing is of cast steel, filled with white metal. The hollow gudgeon pin, of Ubas steel, is shrunk into the connecting rod. The aluminum alloy piston closely followed the design adopted for the "Unit" engine previously described. In view of the results obtained with the "Unit" piston it was thought that the 20 inch piston would probably run satisfactorily without any special means of cooling. As there was, however, a doubt about this it was decided to arrange for oil cooling, and the system adopted followed the lines of that fitted by Messrs. Sulzer. A separate motor-driven pump and cooler are provided for the piston-cooling oil. The recess in the head of the piston is hemispherical. There were two reasons for this, viz., that the hemispherical recess resulted in a combustion chamber of good form which would probably facilitate combustion, and also that by adopting this shape in the design of an experimental engine it enabled pistons having heads of other shapes to be fitted for experiment at a later date, if considered necessary, without any structural alterations. The adoption of this shape of piston head adds several inches to the overall height of the engine, but it is considered that it is justified—especially in the case of an experimental engine.

The cast-steel cylinder cover, or head, was made as simple and as light as possible consistent with stiffness, and care was taken to avoid, where possible, all straight ribbing. Air and exhaust passages are not embodied in the cover. The fuel valve housing, which is amply cooled, connects the top and bottom flanges of the cover and completely surrounds the fuel valve casing. The housings for the air and exhaust valve boxes, which form curved ribs between the top and bottom flanges of the cover, do not completely surround the valve boxes so that the latter are directly in contact with the cooling water. Four large cleaning doors are provided in the sides of the cover. By this design a comparatively simple casting is obtained and, although a considerably reduced depth of cover results from the air and exhaust valve passages not being embodied in the casting, so far as can be seen the cover is stiff enough for all practical purposes—in fact, it may be definitely stated that even when working at high

speeds and high mean pressures it is at least as stiff as the cast-steel covers fitted to the standard submarine engines and which have given practically no trouble on service. The water service is taken from the town's main. Cooling water enters the jacket at two points and passes into the cover and the exhaust valve box. The sandwich plate is separately cooled.

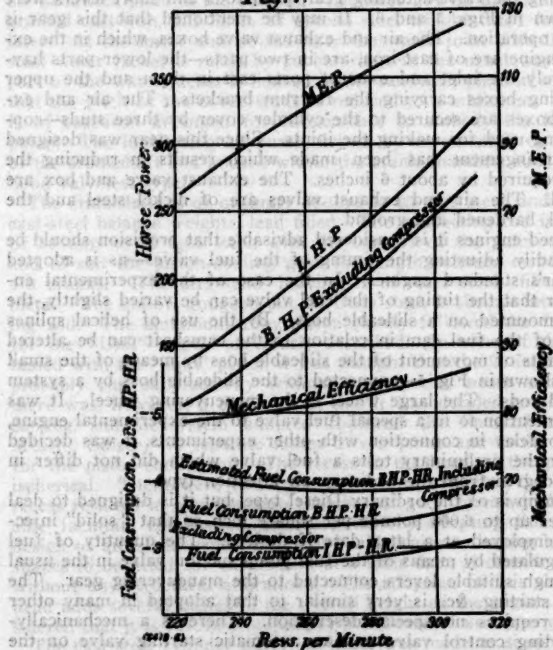
It was considered from the point of view of quiet running that skew gears were preferable to spur or bevel drives. Skew gears were therefore adopted, and as it was desired to arrange for an enclosed cam-case, and at the same time to be in a position to remove the cylinder cover without dismantling the valve-actuating gear, push rods and short levers were used as shown in Figs. 5 and 6. It may be mentioned that this gear is very quiet in operation. The air and exhaust valve boxes, which in the experimental engine are of cast-iron, are in two parts—the lower parts having respectively the inlet and exhaust ports cast in them and the upper parts or spring boxes carrying the fulcrum brackets. The air and exhaust valve boxes are secured to the cylinder cover by three studs—copper rings being used for making the joints. Since this gear was designed a slight rearrangement has been made which results in reducing the head room required by about 6 inches. The exhaust valve and box are water cooled. The air and exhaust valves are of nickel steel and the cams of steel, hardened and ground.

In high-speed engines it is considered advisable that provision should be made for readily adjusting the timing of the fuel valves—as is adopted in the Vicker's standard engines. In the case of the experimental engine, in order that the timing of the fuel valve can be varied slightly, the fuel cam is mounted on a slideable boss. By the use of helical splines the position of the fuel cam in relation to the camshaft can be altered within the limits of movement of the slideable boss by means of the small hand wheel shown in Fig. 5—connected to the slideable boss by a system of levers and rods. The large wheel is the maneuvering wheel. It was the original intention to fit a special fuel valve to the experimental engine, but, owing to delay in connection with other experiments, it was decided to utilize for the preliminary tests a fuel valve which did not differ in any marked degree from the ordinary air-injection type.

The fuel pump is of the ordinary Diesel type, but it is designed to deal with pressures up to 6,000 pounds per square inch so that "solid" injection can be employed at a later date if desired. The quantity of fuel pumped is regulated by means of the fuel pump suction valve in the usual manner, through suitable levers connected to the maneuvering gear. The operation of starting, &c., is very similar to that adopted in many other engines and requires no special description. There is a mechanically-operated starting control valve and an automatic starting valve on the cylinder head—the water-cooled box containing the automatic valve being also utilized for accommodating the relief valve and indicator connection, so that only one hole in the cover is necessary for these fittings. The engine is not reversible. No difficulties are, however, anticipated in connection with the fitting of the reversing mechanism to a multi-cylinder engine—in fact, the drawings have already been completed. The reversing mechanism is one of the simple problems in Diesel design, and there is no doubt that this part of a marine engine has given the least trouble, except in one or two cases where the gear was unsuitable for sea-going conditions. A Ruston standard governor is fitted on the vertical shaft and arranged to cut off the fuel supply when the engine reaches a speed of about 420 revolutions per minute.

The fulcrums for the compound fuel valve actuating levers are carried by a separate casting secured to the cylinder cover—so that there is no fulcrum bracket attached to the fuel valve casing. When the fuel supply is altered the lift of the fuel valve is also modified slightly. The lift of the fuel valve can also be adjusted independently by means of a separate hand-control gear carried on one of the camshaft brackets—but this is intended only for experimental purposes and need not be embodied in a multi-cylinder engine. A cast-steel flywheel, giving a cyclic irregularity

Fig. 7.



of about 1/35, is fitted so that a high peripheral speed can be safely employed. Holes are provided in the rim of the flywheel for taking a turning bar.

Forced lubrication is employed throughout. The cylinder liner and exhaust valve spindle are lubricated by a mechanical lubricator. The indicator gear is of similar design to that already described, and, following the practice adopted in the case of other engines, separate gears are fitted for taking combustion and fuel valve lift diagrams. It was originally intended that the air compressor should be driven by the engine but it was eventually decided, in view of future work, to drive it independently. The power developed by the engine is absorbed by a Heenan and Froude dynamometer. The fuel consumption is measured by weighing the

amount of fuel consumed by the engine, a weighing machine and a fuel tank having the usual narrow neck, in which a point gauge is fitted, being used for the purpose. Other points in connection with this engine require no special reference as they generally follow the ordinary accepted practice. It might be mentioned, however, that in a completed engine aluminium would be made use of as far as possible, although it would not be proposed at this stage to utilize any special steels.

The engine was first started on fuel on October 28 of last year, and short runs were made, using Texas fuel oil, at 250 revolutions per minute, the maximum compression pressure with a compression ratio of 13·15 being 475 pounds per square inch. During these runs no oil was used for cooling the piston. When the piston was examined it was found to be in excellent condition, and it showed an even bed on the liner and it was therefore replaced. The speed and power of the engine were then gradually increased to 350 revolutions per minute and 200 brake horsepower. There were no mechanical difficulties at this speed but it was found that the resistance in the fuel valve to the passage of air and fuel was too great and a number of pulverizer washers were consequently removed. This modification enabled 168 brake horsepower to be developed at 300 revolutions per minute, but the quantity of pulverizing air used was still insufficient—in fact, the fuel valve was working as a very inefficient solid injection valve—and the fuel consumption was 0·6 pound per brake horsepower hour.

The fuel valve of this engine, as in the case of the air-injection valve fitted to the engine previously described, was provided with a distributor containing a large number of small holes so that the air sprays corresponding to each hole could be directed into the combustion chamber in any predetermined direction. This is essential for engines running at high speeds and with comparatively high mean pressures, and it is interesting to note that the fuel valves of the German submarine engines are fitted with multiple hole distributors and other firms have also recently adopted this as standard practice.

In view of the resistance in the fuel valve of the experimental engine it was decided to remove all the pulverizer washers and to replace the distributor by one having a small number of larger holes, as it was desired to limit the pressure of the blast air to 1,000 pounds per square inch when the engine was developing its full output This alteration resulted in 168 brake horsepower being developed at 300 revolutions per minute with a fuel consumption of 0·35 pound per brake horsepower hour—a marked improvement on the result previously obtained. This figure for consumption does not include the power required to drive the air compressor.

At this stage the revolutions of the engine had to be limited to 300 revolutions per minute, and the running generally was considerably restricted owing to complaints in regard to vibration. On a few occasions, however, before the speed was limited the engine had been run at its rated speed with no signs of trouble. It might be mentioned that whilst the balance weights attached to the cranks reduce the magnitude of the vertical unbalanced forces, they introduce a horizontal couple in the athwartship plane, and as the center line of the engine is, on account of the lay-out of the laboratory, unavoidably 11 feet from the ground level, the rocking of the engine at high speeds was fairly marked. As 300 revolutions per minute could not be exceeded, although a few tests were actually run at about 320 revolutions per minute after this time, it was decided to carry out tests at about this speed and at lower speeds with the object of improving the fuel consumption. Typical results obtained are shown in Table III.

The power required to supply the blast air is not accounted for in columns 3, 6 and 10. The compressor used is of the Reavell type, driven by belt from an electric motor. Column 8 gives the horsepowers absorbed by the compressor after making the necessary deductions from the effective horsepower, based on a combined motor and belt efficiency of 85 per cent. The speed of the electric motor can be varied slightly, but beyond this the air delivered in excess of requirements is blown off between the first and second stages. Owing to the design of the compressor it is not possible, as is done in the case of the other experimental engines, accurately to measure the quantity of blast air actually used by the engine when it is running. By noting, however, the time required to pump up the bottles over small ranges of pressure when the compressor is running at the same speeds, &c., as during the tests an approximation can be obtained of the air used, and therefore of the power required to supply this air. It was found that in all cases the powers given in column 8, Table III, exceeded those calculated from the figures obtained for the quantity of air pumped. It was considered desirable, however, to take the higher figures, *i.e.*, those shown in column 8, for estimating the fuel consumption per brake horsepower, including the compressor—shown in column 11, Table III, but it may be pointed out that in the author's opinion these

TABLE III.

1	2	3	4	5	6	7	8	9	10	11
								Fuel Consumption. B.P.-Hour.		Lbs. per
Test No.	B.P.M.	B.H.P.	I.H.P.	M.E.P.	Mechanical Efficiency. Per Cent.	Blast Pressure. Lbs. per Sq. in.	H.P. of Compressor.	I.H.P.	B.H.P. excluding Compressor.	B.H.P. including Compressor (estimated).
24	309	268	310	126	86·4	920	27·3	0·31	0·36	0·4
29	282	212	254	114	83·5	960	27·2	0·29	0·34	0·39
31	242	173	207	100	83·6	680	23·2	0·28	0·33	0·38
40	245	138	174	90	79·4	750	18·2	0·28	0·35	0·4
50	222	106	135	76	78·5	700	17·3	0·27	0·34	0·41

TABLE IV.

1	2	3	4	5	6	7	8	9	10	11
								Fuel Consumption. B.P.-Hour.		Lbs. per
Test No.	B.P.M.	B.H.P.	I.H.P.	M.E.P.	Mechanical Efficiency. Per Cent.	Blast Pressure. Lbs. per Sq. in.	H.P. of Compressor.	I.H.P.	B.H.P. excluding Compressor.	B.H.P. including Compressor (estimated).
24	314	314	373	150	84·1	1,000	24·7	0·30	0·46	0·5
25	313	313	358	144	87·4	1,000	26·7	0·27	0·42	0·48
57	283	286	344	136	84·6	900	25·8	0·33	0·39	0·43
63	284	284	323	143	88·2	1,000	28·2	0·32	0·38	0·4
65	283	283	334	149	84·7	1,000	27·6	0·33	0·39	0·43

TABLE V.—Comparison between German and Admiralty Engineering Laboratory Engines.

Engine.	Cylinder. Diameter.	Stroke.	B.P.M.	Connecting Rod, including Bottom and Top End Brasses.		Piston, complete with Pipes and Guards.	
				Total Weight.	Weight per Square Inch of Piston.	Total Weight.	Weight per Square Inch of Piston.
	In.	In.		lb.	lb.	lb.	lb.
German	20·9	20·5	340	300	2·76	245	2·75
Admiralty Engineering Laboratory	20·0	20·0	350	220	2·01	203	1·6

results are slightly higher than would be obtained if the compressor were driven by the engine and definite fuel consumptions obtained for the net brake horsepower developed. These remarks apply also to the figures given in Table IV.

As already mentioned, the figures given are typical of the results obtained for many tests with distributors having various numbers, sizes and angles of holes, and for convenience they are shown graphically in Fig. 7. The fuel used during all these tests was Texas fuel oil, having a specific gravity of 0·92 at 60 degrees F. The exhaust during these tests was smokeless, but it was found when running at higher mean pressures, just above 130 pounds per square inch, the exhaust became slightly shaded.

A number of tests, many of from 2 hours' to 6 hours' duration, were also carried out at about 300 revolutions per minute, with mean indicated pressures of about 150 pounds per square inch, and with various distributors—the object being further to test the piston. The exhaust during these tests was shaded. The particulars given in Table IV are typical of the results obtained. At the end of 100 hours' running at various powers, the engine was opened out for inspection, and the piston, top-end and bottom-end bearings were found to be in excellent condition. The engine runs smoothly and well at the higher speeds. At the lower powers a very slight piston knock is sometimes noticeable, which would indicate that the piston clearance is slightly greater than necessary at these speeds. There is no knock, however, at the higher powers.

The quantity of piston cooling oil circulated through the system when running at 314 brake horsepower at 314 revolutions per minute was only 210 gallons per hour—the rise in temperature of the cooling oil being 64 degrees F. If we assume, therefore, that the calorific value of the oil is 18,400 British thermal units (lower heating value), the quantity of heat carried away by the cooling oil is about 2·3 per cent of the heat supplied. At lower speeds and also at lower mean pressures at the same speed, the percentage of heat passing to the cooling oil is slightly higher. It would probably be advisable to pass a larger quantity of oil through the piston and reduce the rise in temperature, but so far no alteration has been made to the engine in this direction.

Further tests are, of course, proceeding, and later it will be possible to continue the tests at the higher speeds. So far no mechanical difficulties have been encountered, and it is not anticipated that any trouble will arise which will prevent the engine developing at least the rated net brake horsepower, i.e., the brake horsepower arrived at after making full allowance for the power required to drive the air compressor.

By running an engine at high mean pressures a greater power can be developed in a given space and the weight per brake horsepower is reduced. It is well known that many makers of marine oil engines are of the opinion that it is unwise to work with mean indicated pressures much in excess of 100 pounds per square inch—in fact, the present tendency seems to be to reduce this figure. This is no doubt the result of past experience, and may be desirable in the case of merchant ship engines. The requirements of a naval engine, however, differ considerably from those of a merchant engine, and it is felt that if progress is to be made with naval engines the use of higher mean pressures should be seriously considered. In all the experiments which have been carried out at the Admiralty Engineering Laboratory, therefore, the adoption of high mean pressures has always been kept in mind. It was for this reason that the experimental engine just referred to was designed with a rated mean indicated pressure of about 120 pounds per square inch.

No difficulty has been experienced at the laboratory in running high-speed Diesel engines working on the four-stroke or two-stroke opposed piston cycles, at 130 pounds M.E.P., with a smokeless exhaust when using Texas fuel oil, but in each case air injection has been necessary, as smokeless combustion has not so far been obtained with the solid injection system at mean pressures much in excess of 100 pounds per square inch.

For the pressures above 130 pounds per square inch it is probable that supercharging will be adopted, and the problem of working at these high mean pressures with a smokeless exhaust is primarily one of successful fuel injection—in fact, the fuel injection valve is the heart of the high-speed engine.

At present it is usual to work with a compression ratio as low as possible and to obtain economy by introducing the fuel oil before the top dead center. This results in a rise of pressure at (approximately) the dead center, which in the case of the Laboratory experiments has so far been limited to 630 pounds per square inch. The introduction of supercharging air would result in a high compression pressure with the same compression ratio, and consequently, if it were desired to work with the same limiting maximum pressure after injection, the fuel would have to be injected later. This, apart from other considerations, would result in a slightly higher fuel consumption per horsepower.

The greater charge-weight of air in the working cylinder when supercharged should enable more fuel to be satisfactorily burned, resulting in a higher mean pressure. The temperatures throughout the cycle when working at high mean pressures with supercharging in use would not necessarily be higher than when working with lower mean pressures without supercharging—*i.e.*, temperature difficulties would not be increased as a result of the adoption of supercharging. The supercharging engine would be slightly more complicated, and additional air pumps would be necessary, which would slightly reduce the mechanical efficiency of the engine; but these pumps would have to deal only with comparatively low pressures. It may be taken that if 50 per cent more power was developed by supercharging, approximately 10 per cent would be absorbed in supplying the supercharging air, *i.e.*, there would be a net gain in power of 40 per cent.

A low fuel consumption is not the only desideratum for naval engines, and it is considered, therefore, that supercharging experiments are fully justified, and the 300 brake horsepower experimental engine already described will be modified for this purpose at a later date. In this instance air will be drawn through the inlet valve in the ordinary way, and the supercharging air will be introduced through ports in the liner towards the end of the suction stroke of the piston. The air will be supplied by a rotary blower, and arrangements made so that the blower can be cut out when the supercharging air is not required.

Although it is not proposed to give a description of the large German submarine engines, a comparison between the weights of the piston and connecting rod of the German engine and the Laboratory engine already referred to of approximately the same brake horsepower per cylinder, is given in Table V above.

One of the first starting diagrams taken from the 300 brake horsepower Laboratory engine is shown in Fig. 8. This diagram was taken with an indicator gear 90 degrees out of phase with the ordinary indicator gear. It will be seen from the diagram that when starting air was admitted into the cylinder the piston was in a position corresponding to

A, and the rise of pressure is along the line A B. K C D is the compression curve, and subsequent admissions of starting air are shown by the curves 1, 2, &c. The first ignition of oil is shown by the line E F, the second ignition by G H, and the third by I J. It will be noticed that as the speed of the engine increases the maximum compression pressure increases slightly, and also, omitting the first ignition, the ignition occurs later—the timing gear being kept in the same retarded position throughout. Figs. 9, 10 and 11 are ordinary diagrams representative of those taken from the engine.

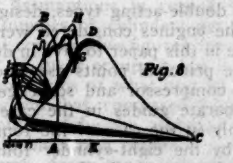
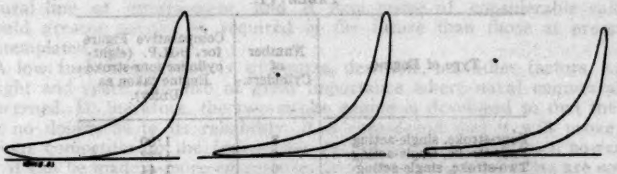


Fig. 8

Fig. 9. CYL. DIA. 20 IN, STROKE 20 IN, R.P.M. 300, M.E.P. 142·5 I.H.P. 339, B.H.P. 300, MECH. EFF. 88·5, FUEL, TEXAS; COMP. PRESS. 480.

Fig. 10. CYL. DIA. 20 IN, STROKE 20 IN, R.P.M. 262, M.E.P. 99·6, I.H.P. 207, B.H.P. 173, MECH. EFF. 83·6, FUEL, TEXAS; COMP. PRESS. 475.

Fig. 11. CYL. DIA. 20 IN, STROKE 20 IN, R.P.M. 222, M.E.P. 76·6, I.H.P. 135, B.H.P. 106, MECH. EFF. 78·5, FUEL, TEXAS; COMP. PRESS. 475.



It is considered unnecessary to refer to the past history of high-speed Diesel engines, as we are principally concerned with the future. It is hoped, however, that in the future technical opinions in regard to the process of development will be more readily accepted than they have been in the past, for there is no doubt that in many instances progress has been arrested by the lack of success which has frequently followed the action taken as the result of the influence of the enthusiastic amateur. If progress is to be made, development must take place step by step—for it is the only sure way.

The high-speed high-duty oil engine is a much more difficult problem than the low-speed low-duty type, and as the Admiralty is the principal user of the former it is reasonable and essential, in the author's opinion, that an Admiralty Laboratory should carry out at least a portion of the experimental work involved in its development. There is no reason for the Laboratory experiments in any way to stifle the initiative of firms or individuals in the development of the high-speed engine, but it is hoped, and expected, that the Laboratory will be the means of assisting and co-ordinating the work. Members of the Institution will doubtless agree that the naval engine should be the best available, and consequently it should embody details which are recognized from time to time as being

the best on the market. This can only be brought about by the Admiralty, and in this connection at least the Admiralty Engineering Laboratory should prove its value.

Comparisons have frequently been made between Diesel engines of various types in regard to power and space occupied, but in many cases such comparisons have either been based on assumptions which could not be wholly accepted or certain assumptions have been taken no doubt with the object of emphasizing the advantages of a particular engine. A short time ago the author had occasion to look into this question with the object of ascertaining the approximate brake horsepower which could be developed by high-duty Diesel engines of the four-stroke single-acting, two-stroke single-acting and two-stroke double-acting types, designed for the same overall length and height. The engines considered were based on Laboratory designs. It is not possible in this paper to give in detail the whole of the assumptions made, but the principal points assumed were: (1) Air injection in all cases; (2) the compressor and scavenge pumps driven from the main engines; (3) separate guides in the case of the two-stroke engines and trunk pistons only in the case of the four-stroke engines. Taking the power developed by the eight-cylinder four-stroke engine as the unit, the comparative figures obtained are shown in Table VI.

TABLE VI.

Type of Engine.	Number of Cylinders.	Comparative Figure for. B.H.P. (eight-cylinder four-stroke Engine taken as Unity).
Four-stroke, single-acting ..	8	1·00
Four-stroke, single-acting ..	6	1·22
Two-stroke, single-acting ..	6	1·44
Two-stroke, single-acting ..	8	1·38
Two-stroke, double-acting ..	6	1·9

With the assumptions taken it will be seen that it is advantageous to keep down the number of cylinders in an engine; also, the increase of power resulting from the adoption of the two-stroke single-acting engine is not very marked. There is a distinct advantage in favor of the two-stroke double-acting engine, but it would be more complicated, and its use could only be justified for higher powers than those at present contemplated.

Although the comparative figures arrived at are correct for the assumptions taken, other points, in addition to space occupied, have to be considered when deciding on the type of engine to be used for powers larger than those at present in use or under construction. The advantages and disadvantages of the various types are well known and need not be discussed in this instance. For powers of the order of 2,000 brake horsepower per engine for high-speed naval work there would be no great difference in the widths of the three types of engines, but as the power increased it is probable that the width of the four-stroke engine would be slightly greater than the widths of the two-stroke engines—at

least so far as the six-cylinder engine is concerned. This would necessitate a wider engine room in order to accommodate pistons and covers when dismantling.

It has been assumed in these comparisons that the four-stroke engines are not fitted with separate crossheads, as in the case of the two-stroke engines. If separate crossheads were fitted, it would be necessary to reduce the stroke of the engine for a given head-room, so that either the piston speed would have to be reduced, or if the piston speed were maintained the inertia forces would be increased. This, in addition to the size of the cylinder, &c., would probably limit the use of four-cycle engines for comparatively high powers.

Other assumptions in regard to the method of driving the scavenge pumps, number of cylinders per engine, &c., could be taken in order to arrive at comparative figures for brake horsepowers solely from the point of view of space occupied, but it is considered that the cases worked out give a good idea of what may be generally expected. It is clear from the results given that, compared with the four-stroke engine, the increase in power obtained by the adoption of the two-stroke single-acting or two-stroke double-acting engine is not so great as is frequently stated.

Although, from the point of view of actual performance under sea-going conditions, the four-stroke engine has proved more reliable than the two-stroke engine for submarine propulsion, the possibilities of the latter cannot be overlooked. The four-stroke engine was the first in the field and has received more attention, but the two-stroke engine is the natural line of development, and it may prove of considerable value should greater powers be required in the future than those at present contemplated.

A low fuel consumption is, of course, desirable, but other factors, *e.g.*, weight and space, are also of great importance where naval engines are concerned. If, therefore, the two-stroke engine is developed so that there are no doubts as to its reliability, it is considered that it will prove a serious competitor to the four-stroke engine, even for moderate powers, for it can be made a more simple engine so far as the vital parts are concerned.

In addition to the engines already mentioned, other engines have been experimented with at the Laboratory and interesting and valuable results obtained, but it is not possible within the limits of this paper to make more than a brief reference to them. The following engines and plant are being experimented with or are under construction, in addition to those already mentioned:—

Opposed-Piston Engine—The opposed-piston type of two stroke engine is represented by a single-cylinder, totally-enclosed engine, which was obtained from Messrs. W. Doxford and Sons, Sunderland. This engine was designed by the firm as an experimental submarine unit, originally for their own use. It follows the firm's usual design, which is generally well known and need not be described here, and has a diameter of 14·55 inches and a combined stroke of 28·3 inches. The double-acting scavenge pump and four-stage air compressor are driven from two cranks on an extension of the engine-shaft. This lay-out for a single-cylinder engine reduces its mechanical efficiency slightly, especially having in view the fact that the scavenge pump and compressor were made larger than necessary for ordinary running, for the purpose of supercharging experiments at a later date.

The engine had not been run when it was delivered to the Laboratory. A large number of tests have now been carried out, and after making

various modifications, particularly to the two fuel valves, very good results have been obtained. The representative results shown in Table VII may be of interest.

Texas fuel oil, having a specific gravity of 0·91 at 60 degrees F, was used for all tests, and the exhaust was clear throughout. The temperature of the exhaust was taken by thermocouple as close up to the exhaust ports as possible. The pressure of the scavenge air in the belt was from 2½ pounds to 3 pounds per square inch.

TABLE VII.

R.P.M.	I.H.P.	B.H.P.	M.E.P.	Mechanical Efficiency, Per Cent.	Blast Pressure, Lb. per Sq. In.	Temperature of Exhaust Gases, Deg. F.	Fuel per H.P.-Hour	
							I.H.P.	B.H.P.
222	500	333	130	66·6	1,525	700	0·33	0·48
205	490	280	129	64·3	1,325	625	0·30	0·47
200	385	220	107	68·0	1,100	575	0·29	0·47
185	305	165	86	60·0	1,000	527	0·29	0·48
140	240	141	87	58·6	900	485	0·28	0·49

The engine runs smoothly and well at all speeds. There have been no important mechanical troubles since a new and stiffer top-end bearing was fitted and slight modifications made to the compressor (principally with the object of keeping the lubricating oil from the walls of the compressor cylinders). The pistons, which have steel heads and aluminium alloy skirts, are cooled with oil. Originally the cooling oil was taken from the lubricating system, but after a few runs it was decided to modify this, and separate tanks and a pump, in this instance driven by a belt from the engine shaft, have been fitted.

The upper piston is fitted with thermocouples, and the results so far obtained indicate that the temperature of the metal at a point ⅛ inch from the surface of the piston, when the engine is developing about 300 brake horspower, is about 630 degrees F. The upper piston is swept by the exhaust gases, whereas the lower piston is swept by the comparatively cool scavenge air, and the temperature of the latter will consequently be less than the former. It was anticipated that higher temperatures would be registered, in view of the thickness of the piston top, but the above figure gives the mean result so far obtained at the power stated. Pistons of different material are now in hand and will be fitted at a later date.

Brief reference might be made to the phenomenon of detonation. In the opposed-piston experimental engine detonation was experienced at the higher powers and speeds, and although not harmful, it would, if heavy, be rather distressing in a multi-cylinder engine. It was very desirable, therefore, that every effort should be made to eliminate the tendency to detonate, but so far it has not been possible to do this completely without at the same time increasing the fuel consumption slightly.

This question was investigated and curves of rate of change of pressure, &c., were obtained from combustion diagrams which clearly indicated that detonation was accompanied by an extremely rapid rise in pressure. From an analysis of the diagrams taken with varying degrees of detonation, the engine developing approximately the same brake horsepower and the same speed throughout, it was found that: (1) An increase in the rate of heat supply, *i.e.*, in the rate of combustion of the fuel, resulted in increased detonation; (2) in the case for low detonation diagrams heat was supplied later in the expansion stroke than in the

case of high detonation diagrams; (3) the maximum and mean temperatures of the cycle were greater in the low detonation diagrams than in the high detonation diagrams; (4) the thermodynamic efficiency was higher in the case of high detonation diagrams than in the case of low detonation diagrams.

From the experiments which were carried out it was clear that detonation was a function of the speed of injection with the particular fuel used (Texas fuel oil), but when working at high mean pressures an increase in the quantity of fuel injected, other conditions remaining the same, tended to decrease detonation, and in this instance the exhaust did not remain colorless.

Compound Internal-Combustion Engine.—The design of this engine, which was the outcome of a proposal and outline sketches submitted by Mr. H. Ricardo to the Internal-Combustion Sub-Committee, was commenced at the Board of Invention and subsequently completed at the Laboratory. It was constructed by Messrs. P. Brotherhood to working drawings supplied by the Laboratory. After a number of tests had been carried out, it was decided that in view of the unavoidable complication of the engine for marine purposes and the pressure of other work to discontinue the experiments for the present. Ordinary town's gas was used for the preliminary tests.

Hot-Bulb Engine.—A 40 brake horsepower single-cylinder Bolinder engine has been obtained, but this will not be erected until the Laboratory is transferred to West Drayton.

30 *Brake Horsepower Single-Cylinder Four-Stroke Diesel Engine.*—This is being constructed principally for use in connection with the testing of fuel oils. Delivery will be made shortly.

Paraffin Engine.—In view of the number of paraffin engines now in use in the Navy, a four-cylinder engine for about 50 brake horsepower has been obtained and tests have commenced.

Two-Stroke Single-Acting Engine.—A single-cylinder single-acting two-stroke engine of about 400 brake horsepower is being constructed for the Admiralty by Messrs. J. S. White and Co., Cowes. The working drawings were undertaken by the firm, the outline design and drawings of various details being provided by the Laboratory.

Two-Stroke Double-Acting Engine.—Although the headroom available in present submarines precludes the use of the double-acting engine, it was felt that from the point of view of general development it was desirable to consider this type. A preliminary design has therefore been made which may be taken up at a later date. It was understood that previous troubles with double-acting engines were largely due to the difficulty of obtaining satisfactory fuel combustion on the under side of the piston. In the Laboratory design, therefore, special attention has been given to this point, as well as to the design of the covers and liner.

Small Plant.—A number of small pieces of apparatus have been designed by the Laboratory and constructed for experiments in connection with fuel injection; the study of the fuel spray; the ignition temperatures of fuel oils from the engineers' standpoint; the testing of white metal for bearings and material for piston rings, &c.

The fuel injection problem is of the utmost importance in connection with the successful development of the high-speed marine oil engine, and it is hoped that it will be possible at a later date to give some information on this subject.

It has frequently been stated that the Continent has been ahead of this country in regard to the development and manufacture of marine oil en-

gines, largely on account of the use of better materials. Although it is thought that in the past there has been a certain amount of truth in this statement, largely due to continental engineers more thoroughly appreciating the value of the metallurgist and metallurgical work, there were, of course, other factors entering into the question which need not be discussed here. It is true that many difficulties in connection with oil engines may be overcome by improvements in, and, if possible, a simplification of, the design, but when developing high-duty engines and apparatus for naval purposes a full knowledge of the properties of the materials employed is absolutely essential. Consequently, if progress is to be made, the engineer and metallurgist must work together—under the same roof—and it is certain that the metallurgical section of the Laboratory which has recently been set up, under the supervision of Dr. O. F. Hudson, will be of the greatest value in elucidating the various problems which frequently arise. In conclusion, the author wishes to express his thanks to the Admiralty for permission to read this paper; also, to the staff of the Laboratory for their valuable assistance in connection with the experiments.—"Engineering."

ITALIAN FLOTILLA LEADERS.

Mainly in consequence of the financial situation, but partly owing to experience gained during the war, the Italian Government proposes to revise its naval policy, and in future to build and maintain only relatively small vessels, such as scouts, destroyers, and submarines. Pursuant to this decision the majority of the armored ships are to be paid off and the battleship *Caracciolo* is to be completed as an oil fuel depôt. So far as is known, the only war vessels now under construction are eight or more flotilla leaders of an unusually powerful type, which, displacing as they do from 1,900 to 2,200 tons, are more akin to small cruisers than torpedo craft proper. Irrespective of these new vessels, the Italian Navy already includes a number of destroyers or flotilla leaders, which are perhaps the most powerful representatives of their type afloat. Although of slightly smaller tonnage than our flotilla leaders of the "Scott" class, the four Italian units of the "Aquila" class, originally designed for Roumania, have a more formidable armament and virtually the same speed. The *Aquila*, *Nibbio*, and *Sparviero* each mount three 6-inch and four 14-pounder guns, and the *Falco* has six 4.7-inch., as compared with a standard armament of five 4.7-inch in the British "Scott" class. In the new Italian leaders, designated as the *Leone* and *Improved Aquila* classes, a uniform battery of eight 4.7-inch is to be mounted, together with six torpedo tubes. Through the courtesy of Messrs. Gio. Ansaldo and Co., of Genoa, a firm whose long and honorable association with Italian naval development is well known, we are able to give below a detailed description of two separate groups of flotilla leaders, recently constructed by them, which embody to a marked degree the essential characteristics of modern Italian torpedo craft. The first group comprises the *Carlo Mirabello*, *Auguste Riboty*, and *Carlo Alberto Racchia*, launched respectively in 1914, 1915, and 1916; the second consists of the *Alessandro Poerio*, *Cesare Rossarol*, and *Guglielmo Pepe*, launched in 1914-15. All six vessels were completed in time to take part in the operations of the war. As their official classification—Esploratori—indicates, they were designed to act as scouts as well as torpedo vessels, and to this end were given dimensions and sea-going qualities superior to the average run of destroyer,

while special regard was also paid to strength of construction. They proved, without exception, to be fast, weatherly vessels, able to keep the sea in nearly any weather likely to be encountered in the Adriatic and the Mediterranean. Their good speed and powerful armament made them more than a match for the largest Austrian destroyers and equally a terror to enemy submarines. Thanks to careful design and skilled workmanship, the propelling machinery developed on trial a power some 20 per cent in excess of contract requirements. The completion of the three *Mirabellos*, which had been ordered at the end of 1914, was somewhat delayed in consequence of labor and material shortage, but these and other difficulties incident to war-time construction were not permitted to prejudice the quality of the work.

We shall deal first with the *Mirabello* class, the principal dimensions of which are as follows:—

Length between perpendiculars	340 feet
Breadth moulded	32 feet
Draught over keel	9.8 feet
Normal displacement	1,570 tons
Ratio of breadth to length	10.395
Block coefficient	0.517 (metric)

Structure of the Hull.—A vertical central keelson runs the entire length at the same height as the double bottom in the engine-room and as the boiler-room floors. The frames are of the usual type, consisting of floor, principal, and reverse angles, channel-shaped at the sides; they are spaced 21.6 inches apart and are joggled to save the weight of strips between them and the outer strakes of the shell plating. In the engine-room special reinforced frames are fitted where possible. The cellular double bottom, of 31½ inch height under the propelling machinery, is arranged for carrying oil fuel. The deck extends from the forward to the after perpendicular; the beams are cut in way of wing cofferdams and are continuous from side to side where no longitudinal water-tight bulkheads are fitted. The forecastle deck is carried aft as far as the forward funnel. Below this deck there is a partial flat forming a 'tween deck of nearly 7 feet 6 inches. Specially strong beams are fitted both under the main and forecastle deck plating at intervals between the ordinary deck beams. Longitudinal lateral girders run beneath the deck fore and aft, and a girder is worked in at each side between the main and forecastle decks.

Internal Compartments and Oil Fuel Service.—The system of main water-tight transverse subdivision is indicated on the drawings shown herewith. The oil fuel compartments, having a total capacity of 8,200 cubic feet, are subdivided into eighteen separate water-tight tanks, of which the ceiling, where not formed by the double bottom inner plating itself, is in all cases at a level below the normal water line of the ship. The tanks can be filled from the exterior at four different stations, two of which are situated in the forward part and two amidships. Oil can also be taken in by means of two steam pumps carried on board; these pumps, of the Simplex type, have a capacity of 32 tons per hour and are housed in separate compartments. They are equipped with piping and valves to permit the transfer, in case of emergency, of fuel from one compartment to another. Four pumps with a capacity of 12 tons per hour convey the oil through heaters and filters to the burners. The oil fuel piping consists of a ring collector with an independent branch to every compartment.

Bilge and Fire Service.—For bilge and fire service there is a main suction pipe of 3 inch clear diameter, with several branches to the bilges, and eight 40-ton steam ejectors. The fire main, of 2.86 inch clear diameter, is fitted below the deck beams. Pipe ends have standard threads and couplings for use with canvas hose. The pumping plant comprises the following:—Two duplex steam pumps, capacity 15 tons per hour, one in each engine-room; one turbo-electric pump, 30 tons per hour, in engine-room aft; one Challenge type portable pump of 5 tons capacity; one Downton pump fitted on deck.

Fresh Water Supply.—Certain of the lateral cofferdams are used for reserve feed water, the total capacity being 33 tons. Drinking water is carried in two independent galvanized tanks with a total capacity of 3 tons. The fore peak tank and a second compartment below the flat are utilized for storing water for washing purposes. These tanks can be filled from the exterior and also by means of the Excelsior quadruple pumps used for filling the gravitation and distributing tanks.

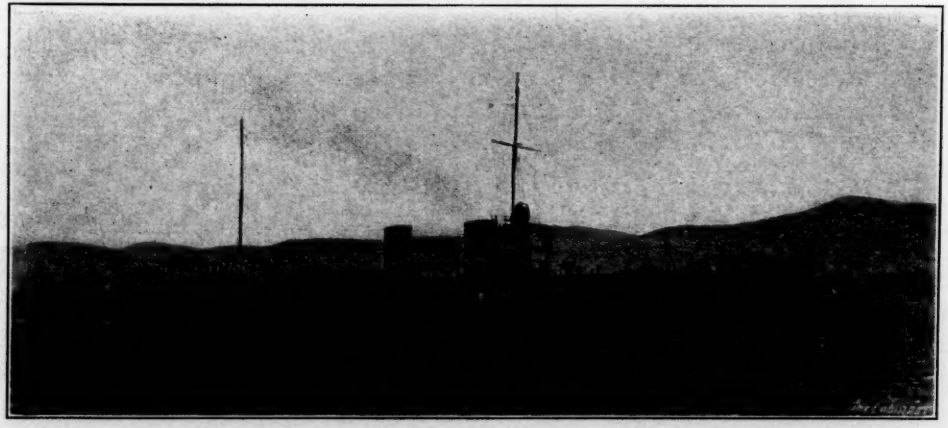
Sanitary Arrangements.—Connections are taken from the fire main to distribute salt water to baths, wash places, and water-closets for officers, warrant officers, and crew. The officers' water-closets are also fitted with small Excelsior pumps for direct service from the sea. Effective sanitation is secured by a small turbo-electric pump of 10 tons capacity hourly, with direct suction from the sea and delivery to the main fire collector pipe.

Ventilation.—Large exhaust fans are fitted in the wardroom, petty officers' mess, and dynamo room, and ventilators in the men's quarters forward.

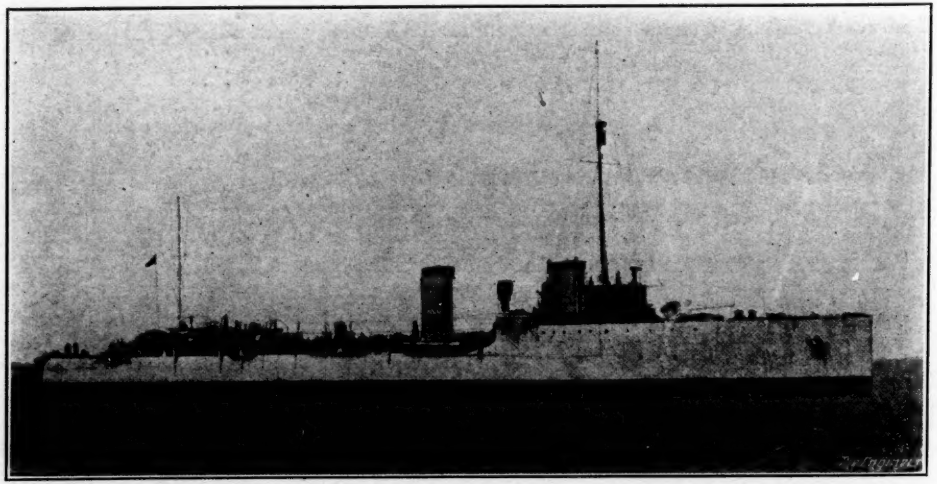
Steering Gear.—Powerful hand and steam steering gears are provided, both working on the double-screw system. The steam steering gear situated in the after engine-room consists of a vertical two-cylinder engine capable of being safely driven at full boiler pressure. Seventy revolutions suffice for putting the rudder from the center to hard over. The hand steering gear has two wheels of the usual large diameter. A suitable arrangement of couplings and pins enables the change over from steam to hand gear to be effected instantaneously. Should the double screw gear be put out of action through damage, resort may be had to an auxiliary mechanical gear, consisting of a toothed sector normally loose on the rudder shaft, which can easily be fixed with strong pins after the cranks of the damaged gear have been dismounted. Furthermore, a reserve bar is provided for working the rudder by hand with tackles.

Anchors, Chains, and Capstans.—The bower anchors are each of 40 hundredweight stockless type, with a shank of forged iron and steel flukes cast in one piece. Nine lengths of cable, each 82 feet long, are provided. Adjacent to the bow there are two electric capstans, each operated independently and having a rotary converter of the closed and ventilated type, which in normal service requires nearly 295 ampères and 105 volts, feeding a motor of 27 horsepower. Transmission is effected by a helicoidal gear, which can be rigidly connected with the capstan by means of skin friction discs. A switchboard for control is fitted under the forecastle. It is possible to weigh the anchors at a rate of 39 feet per second, the normal tension exerted being more than 5½ tons, although for a few moments a maximum pull of nearly 12 tons can be attained. A third electric capstan of smaller type is mounted aft for mooring purposes and for serving the derrick.

Four boats are provided, including a 26-foot petrol launch with a speed of 12 knots.



FLOTILLA LEADER, "POERIO" CLASS.



FLOTILLA LEADER, "MIRABELLO" CLASS.

The masts are built principally of steel, the main mast being reduced in height and of specially stiff construction to obviate the use of shrouds, which interfere with the training of the guns.

All living spaces throughout the ship are sheathed with wooden planking, the decks being covered with linoleum. The washing places have running water with overboard discharge. The ship is heated and lighted by electricity.

The front and sides of the bridge, which is built at a height of 4 feet 8 inches above the forecastle deck, are enclosed by a framing of brass and wood with sliding windows. Below and abaft the bridge are situated a small cabin for the commanding officer, the charthouse and the wireless telegraphy room.

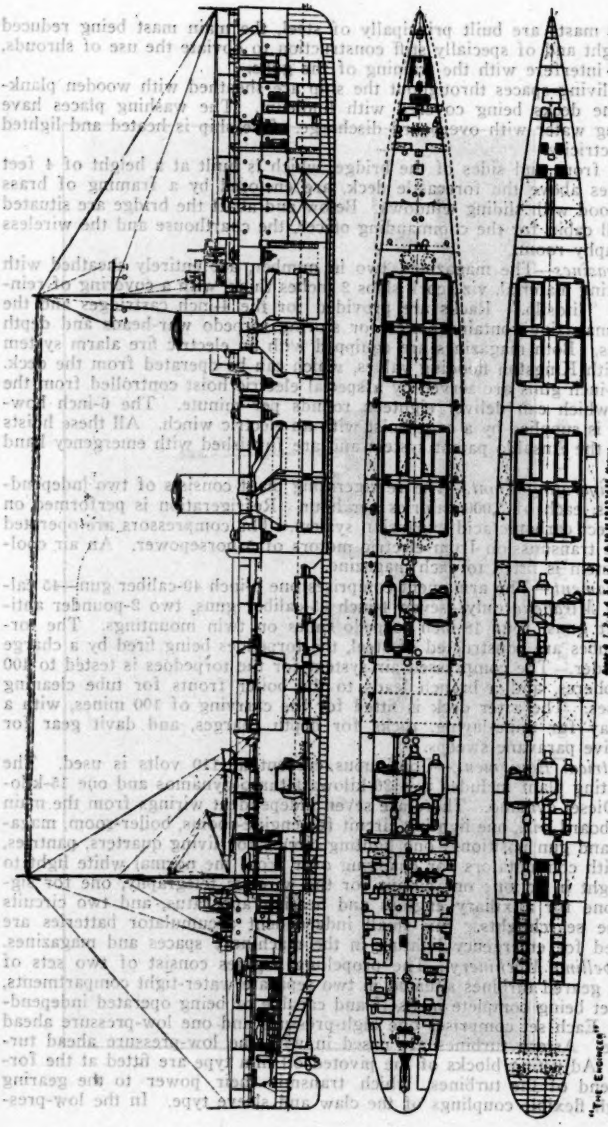
Magazines—The magazines, two in number, are entirely sheathed with insulating material, viz., cork slabs 2 inches thick, with a covering of reinforced "litosilo." Racks are provided for the 4-inch cartridges and the after magazine contains boxes for storing torpedo war-heads and depth charges. Both magazines are equipped with an electric fire alarm system and with Kingston flooding valves, which can be operated from the deck. The 4-inch guns are served by a special electric hoist controlled from the deck, which can deliver eighteen rounds per minute. The 6-inch bow-chaser is supplied by a cage hoist with an electric winch. All these hoists are of the Ansaldo patent system and are furnished with emergency hand gear.

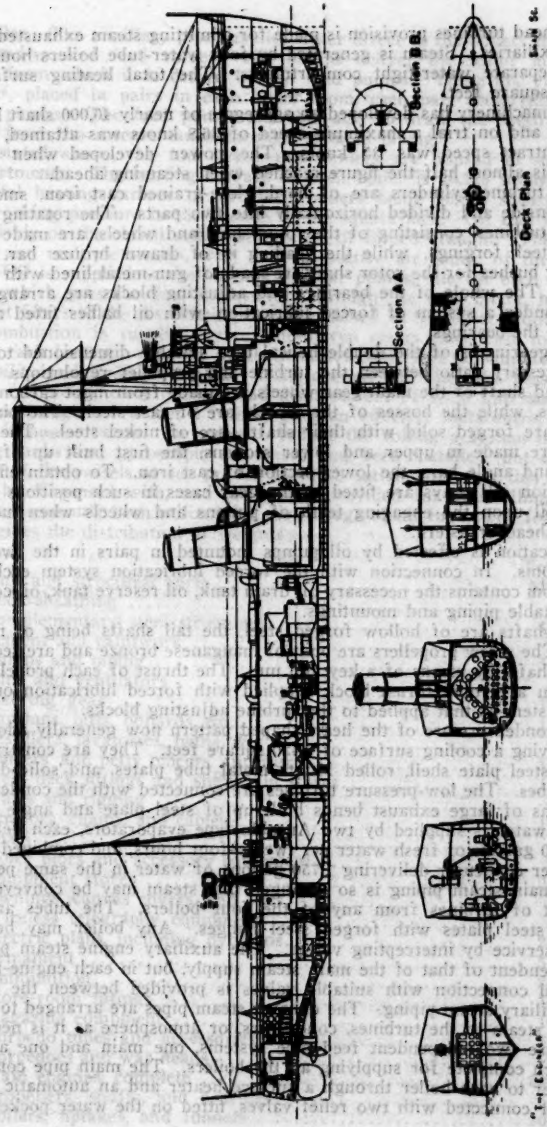
Refrigerating Plant.—The refrigerating plant consists of two independent sets, each of 5,000 calories per hour. Refrigeration is performed on the direct carbonic acid expansion system. The compressors are operated by belt transmission Irom electric motors of 5 horsepower. An air cooling system is fitted to each magazine.

Armament.—The armament comprises one 6-inch 40-caliber gun—45 caliber in *Mirabello* only—seven 4-inch 35-caliber guns, two 2-pounder anti-aircraft guns, four 18-inch torpedo tubes on twin mountings. The torpedo tubes are constructed of steel, the torpedoes being fired by a charge of powder. The compressed air system for the torpedoes is tested to 400 atmospheres, and a branch leads to the boiler fronts for tube cleaning purposes. The after deck is fitted for the carrying of 100 mines, with a tramway for mine-laying, racks for depth charges, and davit gear for explosive paravane sweeps.

Electrical Equipment.—Continuous current at 110 volts is used. The generating plant includes two 30-kilowatt turbo-dynamos and one 15-kilowatt Diesel dynamo. There are seven independent wirings from the main switchboard, *viz.*, one lighting circuit for engine-rooms, boiler-room, magazines, and gun positions; one lighting circuit for living quarters, pantries, &c., with commutators for changing over from the normal white light to blue light in action; one circuit for the wireless telegraphy, one for signals, one for auxiliary engines and heating apparatus, and two circuits for the searchlights. Six small independent accumulator batteries are supplied for emergency lighting in the machinery spaces and magazines.

Propelling Machinery.—The propelling engines consist of two sets of simple geared turbines situated in two separate water-tight compartments, each set being complete in itself and capable of being operated independently. Each set comprises one high-pressure and one low-pressure ahead turbine. Astern turbines are cased in with the low-pressure ahead turbines. Adjusting blocks of the pivoted oil film type are fitted at the forward end of the turbines, which transmit their power to the gearing through flexible couplings of the claw and sleeve type. In the low-pres-


ITALIAN FLOTILLA LEADER, NEMBRICO CLASS.
"THE ENGINEER"


Section BB
Deck Plan
Section AA
ITALIAN FLOTILLA LEADER, POERIO CLASS

sure ahead turbines provision is made for admitting steam exhausted from the auxiliaries. Steam is generated by four water-tube boilers housed in four separate water-tight compartments. The total heating surface is 40,900 square feet.

The machinery has developed an aggregate of nearly 46,000 shaft horse-power, and on trial a maximum speed of 36.8 knots was attained, while the contract speed was 35 knots. The power developed when going astern is almost half the figure reached when steaming ahead.

The turbine cylinders are of hard, close-grained cast iron, smoothly bored inside and divided horizontally into two parts. The rotating parts of the turbines, consisting of the rotor shaft and wheels, are made from ingot steel forgings, while the blading is of drawn bronze bar. The bearing bushes for the rotor shaft are made of gun-metal lined with white metal. The whole of the bearings and adjusting blocks are arranged to work under a system of forced lubrication, with oil baffles fitted at the ends of the bearings.

The gearing is of the double helical type suitably dimensioned to give the necessary ratio between the turbine and propeller revolutions. The rims and shaft of the main gear wheels are made from ingot carbon steel forgings, while the bosses of the wheels are of cast steel. The pinions, which are forged solid with their shafts, are of nickel steel. The gear cases are made in upper and lower sections, the first built up of steel plates and angle bars, the lower section of cast iron. To obtain efficient lubrication oil sprays are fitted to the gear cases in such positions as to spray oil upon the engaging teeth of pinions and wheels when moving either ahead or astern.

Lubrication is effected by oil pumps mounted in pairs in the two engine-rooms. In connection with the forced lubrication system each engine-room contains the necessary oil drain tank, oil reserve tank, oil cooler, and suitable piping and mountings.

The shafts are of hollow forged steel, the tail shafts being of nickel steel. The screw propellers are built of manganese bronze and are secured to the shafts by means of a key and nut. The thrust of each propeller is taken on a pivoted thrust block supplied with forced lubrication on the same system as that applied to the turbine adjusting blocks.

The condensers are of the heart-shaped pattern now generally adopted, each having a cooling surface of 9,420 square feet. They are constructed with a steel plate shell, rolled Muntz metal tube plates, and solid-drawn brass tubes. The low-pressure turbines are connected with the condensers by means of large exhaust bends built up of steel plate and angle bars.

Feed water is supplied by two Ansaldo type evaporators, each delivering 4,400 gallons of fresh water per twenty-four hours, and combined with a distiller condenser delivering 1,750 gallons of water in the same period.

The main steam piping is so arranged that steam may be conveyed to each set of turbines from any of the four boilers. The tubes are of welded steel plates with forged steel flanges. Any boiler may be cut out of service by intercepting valves. The auxiliary engine steam piping is independent of that of the main steam supply, but in each engine-room a special connection with suitable valves is provided between the main and auxiliary steam piping. The exhaust steam pipes are arranged to lead exhaust steam to the turbines, condensers, or atmosphere as it is needed. There are two independent feed pipe systems, one main and one auxiliary, each complete for supplying all the boilers. The main pipe conveys the water to each boiler through a surface heater and an automatic feed regulator connected with two relief valves, fitted on the water pockets of

the boiler. The auxiliary pipe supplies water direct to the boilers through the hand-worked feed valves. Air pumps deliver the water into the tanks, from which it is drawn by the feed pumps. These are eight in number, placed in pairs in each boiler-room, each pair comprising two single pumps. The feed pumps are able also to draw the fresh water direct from the reserve tanks through suitable piping.

As stated above, the four water-tube boilers are housed in separate compartments. The heating surface of each boiler is 10,225 square feet, the total heating surface of the four boilers being 40,900 square feet. The working pressure is 250 pounds to the square inch. Oil fuel is used exclusively on the closed stoke-hold system of forced draught. There are single and multiple sprays, with their respective air cones, of the usual type. Oil is supplied to the burners by four pumps, one for each boiler-room, which pass the fuel successively through the cold filters, heaters, and hot filters to the distributing valves attached to the boiler fronts. Air for combustion is supplied by turbine-driven steam fans, two for each boiler, each having a capacity of about 32,000 cubic feet per minute.

Stability and Rolling.—Stability trials carried out when the vessel was nearly completed, on a normal load displacement of 1,530 tons and with a mean draught of 9 feet 2 inches, gave an effective metacentric height of 30 inches—0.762 m. In order to reduce the rolling a system of anti-rolling tanks and gyroscopic stabilizers had been installed, but the behavior of the vessels at sea proved to be so satisfactory that this system could be dispensed with, and the spaces provided for anti-rolling tanks have consequently been utilized for the storage of oil fuel. The following table gives the distribution of weights:—

	Tons.
Hull and structural parts	512.4
Deck sheathing	9.5
Complementary steel structures	18.2
Cement and paintwork	8.4
Pumps and piping	18.0
Fans and ventilators	6.2
Steering gear	12.8
Capstans, bitts, bollards, &c.	14.2
Distillers, lavatories, baths, &c.	9.0
Officers' and petty officers' furniture	12.0
Mess deck fittings and shelves in stores	13.0
Masts and rigging	2.6
Anchors, chains, and cables	19.0
Boats	4.0
Voice pipes and accessory equipment	2.5
Equipment stores	20.0
Awnings, canvas covers, and sails	1.2
Wireless telegraphy equipment	2.7
Electric plant, including dynamos	28.9
Armament	53.3
Ammunition	22.0
Store-room fittings	10.4
Magazine equipment	16.8
Torpedo tubes and accessories	12.9
Torpedoes and war heads	4.4
Main engines, complete	239.6
Propellers, shafts, and bearings	52.2
Boilers, uptakes, and funnels	305.2

Spare parts, ladders, &c.	27.4
Water in boilers and condensers	62.3
Consumable stores	6.0
Complement and appurtenances	15.0
Drinking water	3.0
Washing water (normal)	10.0
Washing water (extra)	10.0
Reserve feed water	32.9
Oil fuel in filter tanks	47.9
Oil fuel in compartments (normal)	213.6
Oil fuel in compartments (extra)	112.5
Total (full load displacement)	1,972.0

The three vessels of the *Alessandro Poerio* class, comprising the name ship, the *Cesare Rossarol*, and *Guglielmo Pepe*, are somewhat smaller than the *Mirabellos*. Their principal dimensions are:—

Length between perpendiculars	278.88	feet
Breadth moulded	26.25	feet
Draught	8.60	feet
Normal displacement	930	tons
Ratio of length to breadth	10.5	
Block coefficient	0.505	(metric)

In these vessels, as in the preceding class, high-tensile steel has been largely employed, especially for the shell and deck plating. Details of the vessels are shown in the engravings on a preceding page. The oil fuel compartments are furnished with pipes of a number and diameter sufficient to permit the filling of all tanks in a space of two hours. The pumping system for bilge, fire, and fresh water service and the sanitary arrangements are, generally speaking, very similar to those in the *Mirabello* class, of which these vessels are smaller editions.

The armament consists of two 4.7-inch 40-caliber guns mounted respectively on the forecastle and quarter deck; four 3-inch 40-caliber guns on the broadside; and four 18-inch torpedo tubes on two twin-deck mountings. Each of the two magazines contains 260 rounds for the 4.7-inch guns and 560 rounds for the 3-inch. The hoists are worked by hand. Eight torpedoes are carried, four of which are in the tubes and four in reserve. The electric plant is operated by two 30-kilowatt generators with turbo-motors. The propelling machinery resembles in all essential features that of the *Mirabello* class. The maximum power developed on the trial runs was 25,200 shaft horsepower, equivalent to a speed of 33.4 knots. Although of comparatively moderate dimensions, these vessels have an extensive cruising radius, *viz.*, 750 miles at full speed and 3,000 miles at a speed of 15 knots.—"The Engineer."

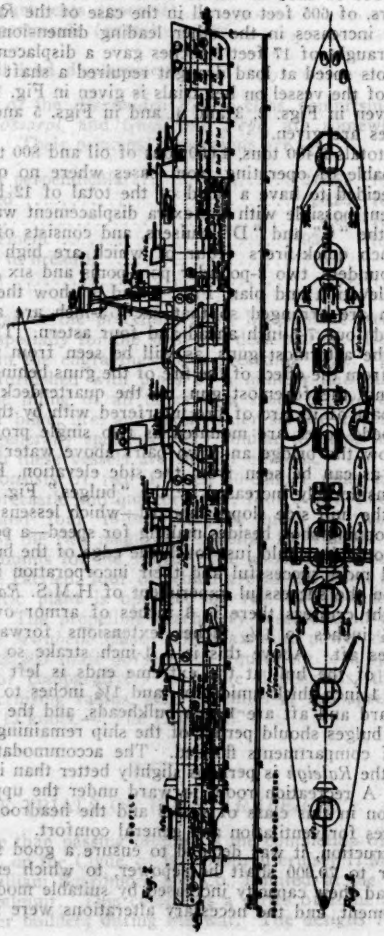
THE TRIALS OF H.M.S. "*RALEIGH*."

An event of more than passing interest is the completion of the steaming trials, last week, on the Clyde, of the armored cruiser H.M.S. *Raleigh*, built by Messrs. William Beardmore and Co., Limited, at the Naval Construction Works, Dalmuir. This completes a series of some 30 war vessels delivered by her builders during the war. The designs for this par-

ticular class of ship were prepared in the summer of 1915, but the completion of construction was delayed because of the inevitable changes of the programme of naval construction due to the necessities of the various phases of the war. The leading consideration was suitability for ocean work in any part of the world, so that a large radius of action was essential. Moreover, to act as a flagship of cruiser squadrons of "C" and "D" class cruisers a speed of at least 29 knots would be required. These features necessitated an increase in size. The 420-foot length of the "C" class and the 445-foot of the "D" class were increased to 565 feet between perpendiculars, of 605 feet overall in the case of the *Raleigh* class, with corresponding increases in the other leading dimensions. A beam of 65 feet with a draught of 17 feet 3 inches gave a displacement in tons of 9,700, and 30 knots speed at load draught required a shaft horsepower of 60,000. A view of the vessel on her trials is given in Fig. 1, while elevations, etc., are given in Figs. 2, 3 and 4, and in Figs. 5 and 6 illustrations of the turbines are given.

The fuel carried totals 2,400 tons, 1,600 tons of oil and 800 tons of coal. In order to be capable of operating from bases where no oil might be available, it was decided to have a third of the total of 12 boilers coal-fired. The armament possible with the extra displacement was a considerable increase on the "C" and "D" cruisers, and consists of seven 7·5-inch guns, ten 3-inch quick-firers (four of which are high angle anti-aircraft), four 3-pounders, two 2-pounder pom-poms and six 21-inch torpedo tubes. The elevation and plan, Figs. 2 and 3, show the disposition of the guns, which are arranged so that six 7·5-inch are available on either broadside and four 7·5-inch ahead and four astern. The crews of the foremost and the aftermost guns, as will be seen from the illustration, are protected from the effect of the fire of the guns behind and above by blast screens, and the foremost gun on the quarterdeck is suitably masked over that part of its arc of fire interfered with by the aftermost gun. The six torpedo tubes are mounted as two single projectors in a submerged flat below the bridge and two pairs above water at the base of the main mast, as can be seen from the side elevation, Fig. 4. The normal beam is considerably increased by the "bulges," Fig. 4, although owing to the way the hull side slopes inboard—which lessens the risk of penetration by a dropping shot, besides making for speed—a perpendicular dropped from the top side would just touch the edge of the bulge. These bulges have proved most successful and their incorporation in this class of vessel follows on the successful experiment of H.M.S. *Ramillies*. As in the previous light cruisers there is 3 inches of armor over the side amidships with 2½ inches to 1⅛ inches extensions forward and 2½ inches to 2¼ inches aft. Above this is a 1-inch strake so that only a very small portion of the hull at the extreme ends is left unprotected. The upper deck is 1 inch thick amidships, and 1½ inches to 1 inch over the rudder. Forward and aft are 1-inch bulkheads, and the combination of subdivision and bulges should permit of the ship remaining afloat with a large number of compartments flooded. The accommodation for officers and crew in the *Raleigh* is perhaps slightly better than is usual with this class of ship. A recreation room forward under the upper forward gun is an innovation in this class of vessel and the headroom of 8 feet between decks makes for ventilation and general comfort.

During the construction, it was decided to ensure a good speed by increasing the power to 70,000 shaft horsepower, to which end the four coal-fired boilers had their capacity increased by suitable modifications to the oil-firing equipment, and the necessary alterations were made to the



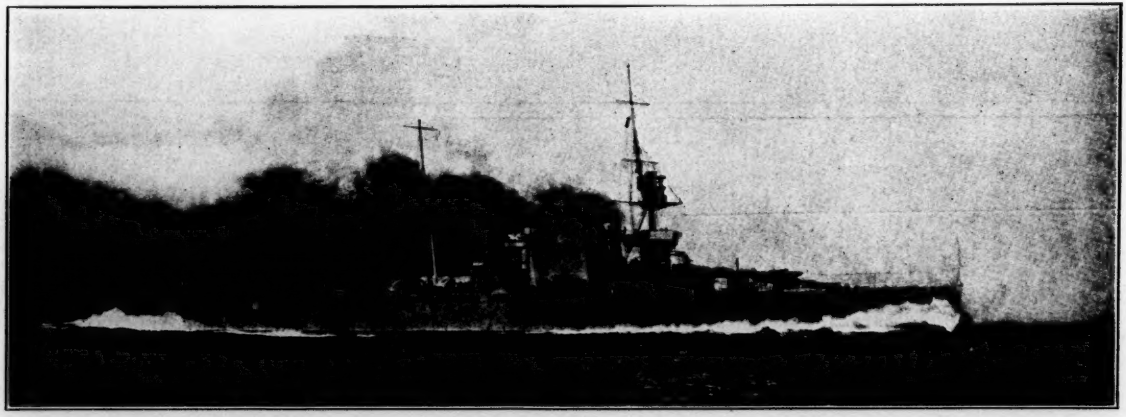


FIG. 1.—VIEW OF THE VESSEL ON THE MEASURED MILE.
H.M. ARMORED CRUISER "RALEIGH."
CONSTRUCTED BY MESSRS. WILLIAM BEARDMORE AND CO., LIMITED, ENGINEERS AND SHIPBUILDERS, DALMUIR.

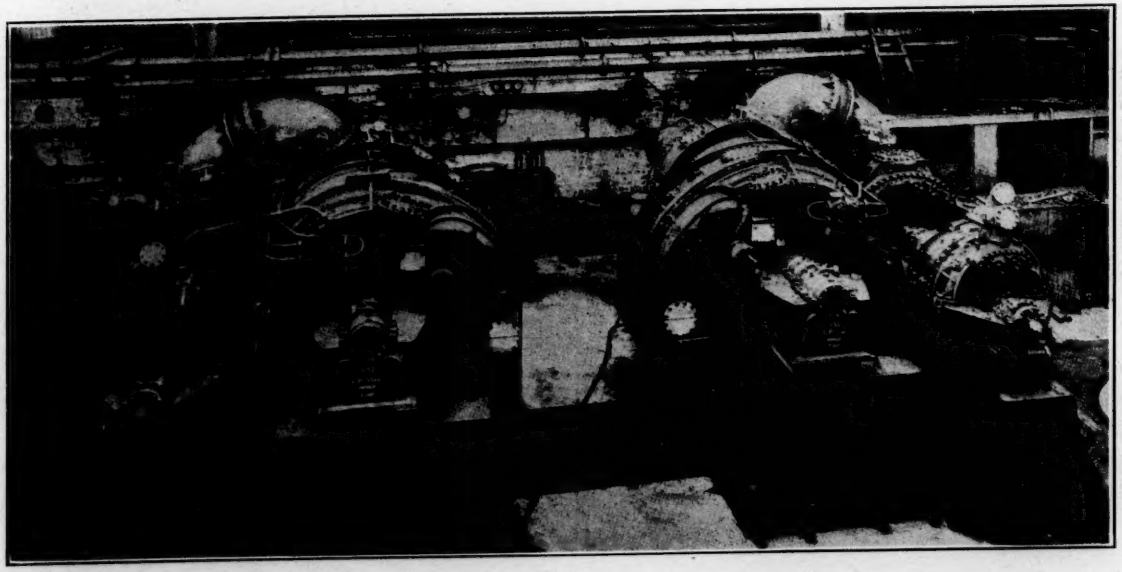


FIG. 5.

GEARED TURBINE PROPELLING MACHINERY OF H.M.S. "RALEIGH."
CONSTRUCTED BY MESSRS. WILLIAM BEARDMORE AND CO., LIMITED, ENGINEERS, DALMUIR.

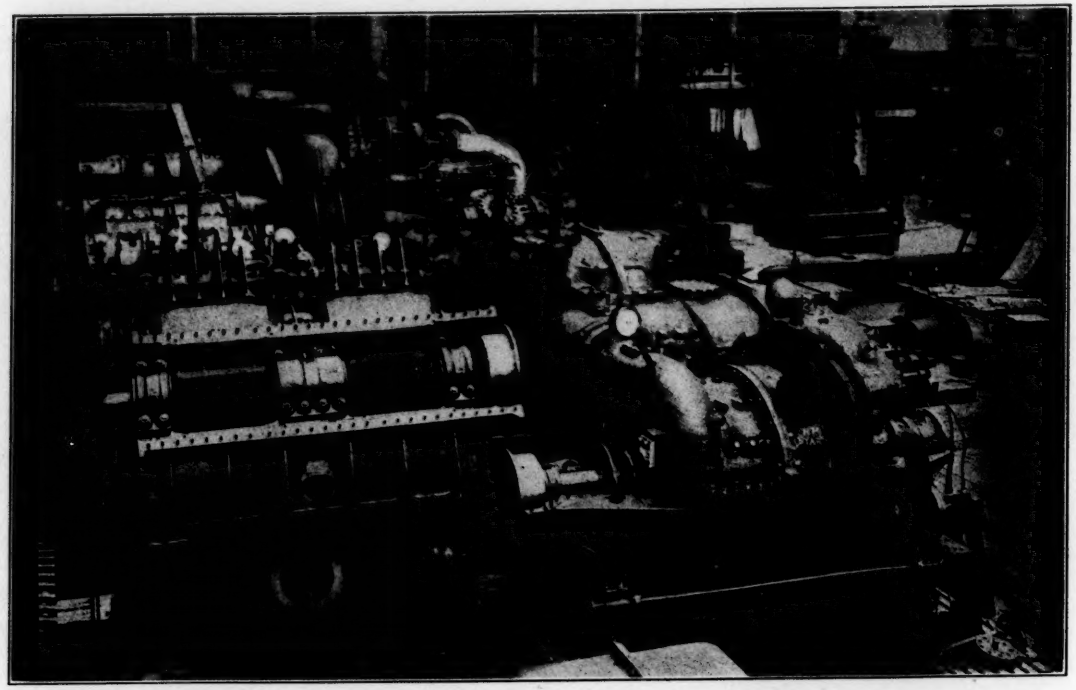


FIG. 6.
GEARED TURBINE PROPELLING MACHINERY OF H.M.S. "RALEIGH.
CONSTRUCTED BY MESSRS. WILLIAM BEARDMORE AND CO., LIMITED, ENGINEERS, DALMUIR.

turbines to take the larger quantity of steam generated. The machinery presents features of interest as showing the solution adopted to install such a large power in the very limited space available. There are altogether 12 boilers—eight oil fired and four coal and oil-fired, of the Yarrow water-tube type. The eight oil-fired boilers have 7,650 square feet of heating surface each. The figures for the boilers using coal and oil are 4,675 square feet of heating surface and 77·58 square feet grate area each. The latter boilers are located in the aft boiler room. The general arrangement of boilers, back to back in the forward and aftermost boiler rooms, but with the firing platform in the center in the middle boiler room, facilitates the lead of the uptakes to the two funnels. To the larger funnel the uptakes from six oil-fired boilers are led, and to the other the uptakes are taken, serving two oil-fired and four coal and oil boilers.

The main machinery consists of four identical sets—two port and two starboard, each of three turbines of the Brown-Curtis impulse type. The cruising turbine is connected by a clutch direct to the forward end of each high-pressure turbine, which is connected in turn by a flexible coupling to the high-pressure pinion of the single-reduction double-helical gearing. The low-pressure turbine is similarly connected to its gearing. Figs. 5 and 6 give general views of the two sets of four turbines showing the turbines lined up to their gearing in Messrs. Beardmore's shops for steaming and balancing. In Messrs. Beardmore's engine shops the appliances available for testing the turbines under steam and the gearing at full speed are particularly complete. A battery of boilers of ample capacity and the necessary condensers, air, circulating and forced lubrication pumps are installed. In Fig. 6 the gear-case and gearing are more distinctly shown, the top part of the gear-case being lifted up and supported on columns and the pinion covers removed, so that the pinion with its bearings as well as the main gear wheel can be clearly seen. The two outer propellers are driven by machinery in the forward engine room, and the two inner from the after engine room. The speeds of the turbines at full power are for the high-pressure 3,200 revolutions per minute, and the low pressure 2,150 revolutions per minute, with the propeller running at 420 revolutions per minute. All the shafts are fitted with Michell thrust bearings. A similar type of bearing is provided for taking the steam thrust of the turbines.

With this class of ship the auxiliary equipment forms a very important part of the whole machinery. The most important items of the present installation are as follows: Fifteen Weir's feed pumps, ten main and five auxiliary. For the three boiler rooms there are 12 steam engine-driven fans, supplied by Messrs. Paul, of Dumbarton. The oil fuel pumps, heaters and filters are accommodated in the boiler rooms; four Weir's dual air pumps and two Allen's circulating engines and pumps are disposed in each engine room. For electric power and light there are two Allen dynamos driven by compound reciprocating engines of a capacity of 105 kilowatts in each engine room. The main steering engines of Bow and McLachlan's build, are located on the after bulkhead of the after engine-room, and are each of the three-cylinder type, one engine being ample for the power and the other being a standby. For auxiliary steering gear the Hele-Shaw electric type is installed in an auxiliary steering compartment aft. Due to a recent decision that this ship should be a flagship in tropical climates, extra refrigerating machinery was installed.

The vessel was taken to the Tail of the Bank on Sunday, September 5, and there commissioned for trials. On Monday she proceeded down the Firth for her preliminary progressive and full-power trials, which were thoroughly satisfactory, and final progressive trials, working up to full-

DALMUIR.

power trials of 4 hours' duration, were run successively on Tuesday, Wednesday and Thursday, September 7, 8 and 9. The various powers at which these trials were carried out were 3,000, 8,000, 15,000, 24,000, 35,000, 55,000, and full power of 71,350 shaft horsepower. At full power the excellent speed of 31 knots was attained as measured by four single runs on Arran double mile. On the progressive trials the cruising turbines were thoroughly tested, and the records of steam and oil consumption go to show a saving of oil fuel of some 15 per cent to 20 per cent at the economical cruising speed of 16 knots to 17 knots, due to the extra expansion of the steam possible by utilizing the cruising turbine at the forward end of the high-pressure turbine. A remarkable feature of the performance of the machinery with this vessel was the fact that with one-half the nominal power, that is, 35,000 shaft horsepower, a speed of 28 knots was measured on the course.

During all these trials the ship proved herself a remarkably steady gun-platform and, except on the steering flat aft above the propellers, there was little evidence that anything like such high speeds were being attained. The machinery ran remarkably well and the noise of the gearing was not obtrusive. On Saturday, September 11, the *Raleigh* left for Devonport where she will be finally completed for her commission as flagship.—"Engineering," September 24, 1920.

NEW COAST GUARD CUTTERS.

Four Coast Guard cutters, the best vessels of their type ever laid down for the United States government, are building at the yard of the Union Construction Company, Oakland. The addition of these vessels to the Coast Guard fleet will be welcomed by American shipowners, who had become deeply concerned at the low state into which the service had fallen, due to the lack of vessels. Both the American Steamship Owners' Association and the Pacific American Steamship Association, the two important societies of owners and operators, had supported a movement to amalgamate the Coast Guard service and the Navy, in the belief that the union of the two closely related services would result in a marked improvement; the adjournment of Congress, without action on either of two bills providing for the amalgamation, leaves the question still unsettled; but, regardless of what Congress does in regard to the proposal, the new cutters will be a most important addition to the facilities for the protection of shipping.

AVERAGE AGE NINETEEN YEARS.

At the present time, the Coast Guard service has twenty cruising vessels, the average age of which, however, is nineteen years and the average speed only twelve knots. Twelve of the vessels, says a memorandum drawn by Robert F. Hand, assistant manager of the foreign shipping department, Standard Oil Company of New Jersey, are more than twenty years old, and one vessel, the *Bear*, was built in 1874. When Mr. Hand drew up his memorandum (in May) five of the cutters were laid up, some because there was no money with which to make repairs, and others because of insufficient complements for their operation. During the war, too, the *McCulloch*, *Mohawk* and *Tampa*, all first-class vessels, were lost. All of these facts explain why the construction of the new cutters is of more than usual interest.

The four cutters will be relatively short (240 feet over-all), which permits building two on the same way. The first pair probably will be launched late this year and the second pair will follow within a few months. In the awarding of this contract to the Union Construction Company the Coast Guard service paid the yard a high compliment, because quality of work is much more important than price.

Besides the cutters, a sea-going tug also will be built by the Union Construction Company. These five vessels, and the Standard Oil Company's Diesel tanker *Charlie Watson*, the latter of which was launched in August, will be among the more interesting new works of the year on the Pacific Coast. The *Charlie Watson* was described at length in Pacific Marine Review for January, 1920.

These are the general specifications for the four new cutters: Length over-all, 240 feet; length on water-line, 220 feet; beam molded, 39 feet; depth at side, amidships, top of keel to upper-deck sheer, molded, 25 feet six inches; displacement at about 14 feet mean draft, with 90,000 gallons of fuel oil, 24,000 gallons of fresh water and 35 tons of stores, 1,600 tons; electric main drive, turbo-electric generator, single screw; estimated shaft horsepower, 2,600; two watertube boilers, 200 pounds working pressure; speed on trial, about 16 knots. The approximate cost of the four cutters and the tug will be $3,500,000.

One steam turbine, direct-connected to an alternating current generator, the generator furnishing current to drive a synchronous motor on the main shaft, make up the propelling machinery. This will be manufactured by the General Electric Company. The maximum steam pressure at the turbine will be 200 pounds' gauge, with 75 degrees superheat and exhausting at 28-inch vacuum. The main generator will be a three-phase, two-pole alternating-current generator running at about 3,000 revolutions per minute, with an output of about 2,040 kilowatts at 2,300 volts. There will be one synchronous motor, 46-pole, 2,600 horsepower, 130 revolutions a minute, 2,300 volts, 50 cycles.

Two Babcock & Wilcox watertube boilers will supply steam for the turbine. These boilers will be constructed for a working pressure of 200 pounds a square inch and from 50 to 75 degrees superheat. Exclusive of superheaters, the boilers will have a total heating surface of 5,800 square feet; will have the closed stoke-hole system of forced draft; a total furnace volume of 600 cubic feet; and will be fitted for burning oil, eight oil-burner units to be installed. These last will be of the mechanical-atomization type. The condenser will have 3,600 square feet of cooling surface. One thousand gallons of fresh water daily will be the capacity of the evaporating plant.

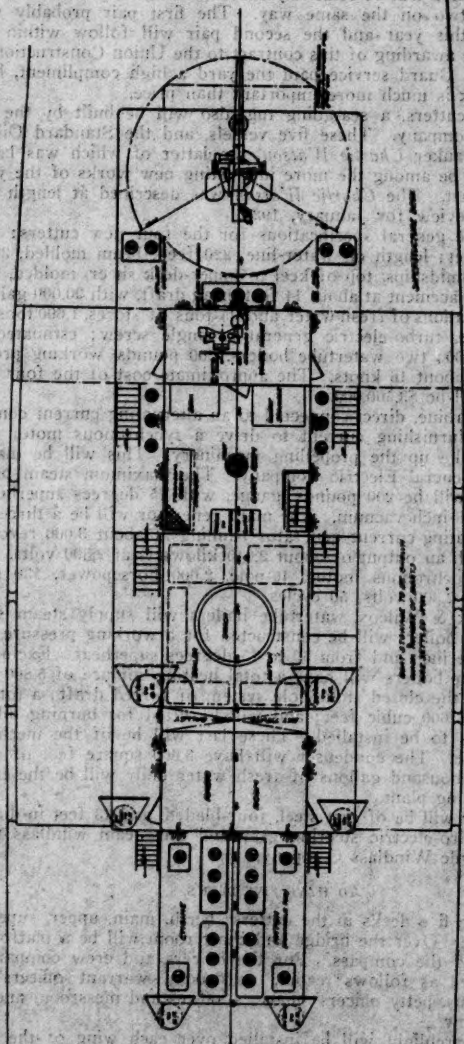
The propeller will be of cast steel, four-bladed, and 13 feet in diameter.

Both the hydro-electric steering gear and the steam windlass will be built by the Hyde Windlass Company.

TO HAVE FIVE DECKS.

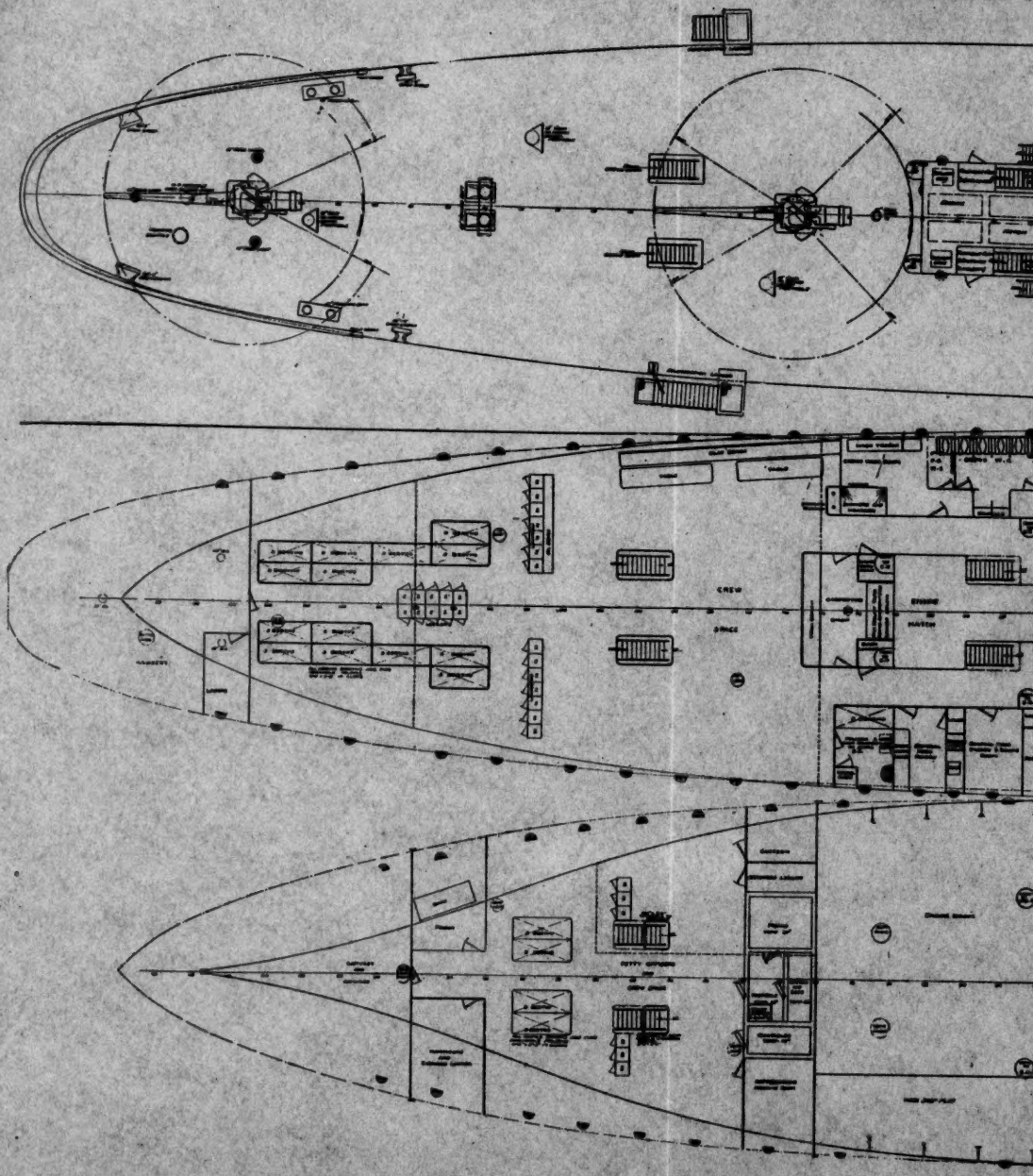
There will be five decks in the cutters: berth, main, upper, superstructure and bridge. Over the bridge and chart room will be a platform for searchlights and the compass. For the officers and crew compartments will be provided as follows: cabin, wardroom, warrant officers' messroom, staterooms, petty officers' quarters, offices and messroom and quarters for the crew.

A 30-inch searchlight will be installed over each wing of the bridge, control being of the pilot-house type, and each searchlight being on an individual circuit direct from the switchboard in the engine-room. On



PLAN OF SUPERSTRUCTURE DECK OF NEW COAST GUARD CUTTERS BUILDING AT THE UNION CONSTRUCTION COMPANY.

DECK PLANS OF



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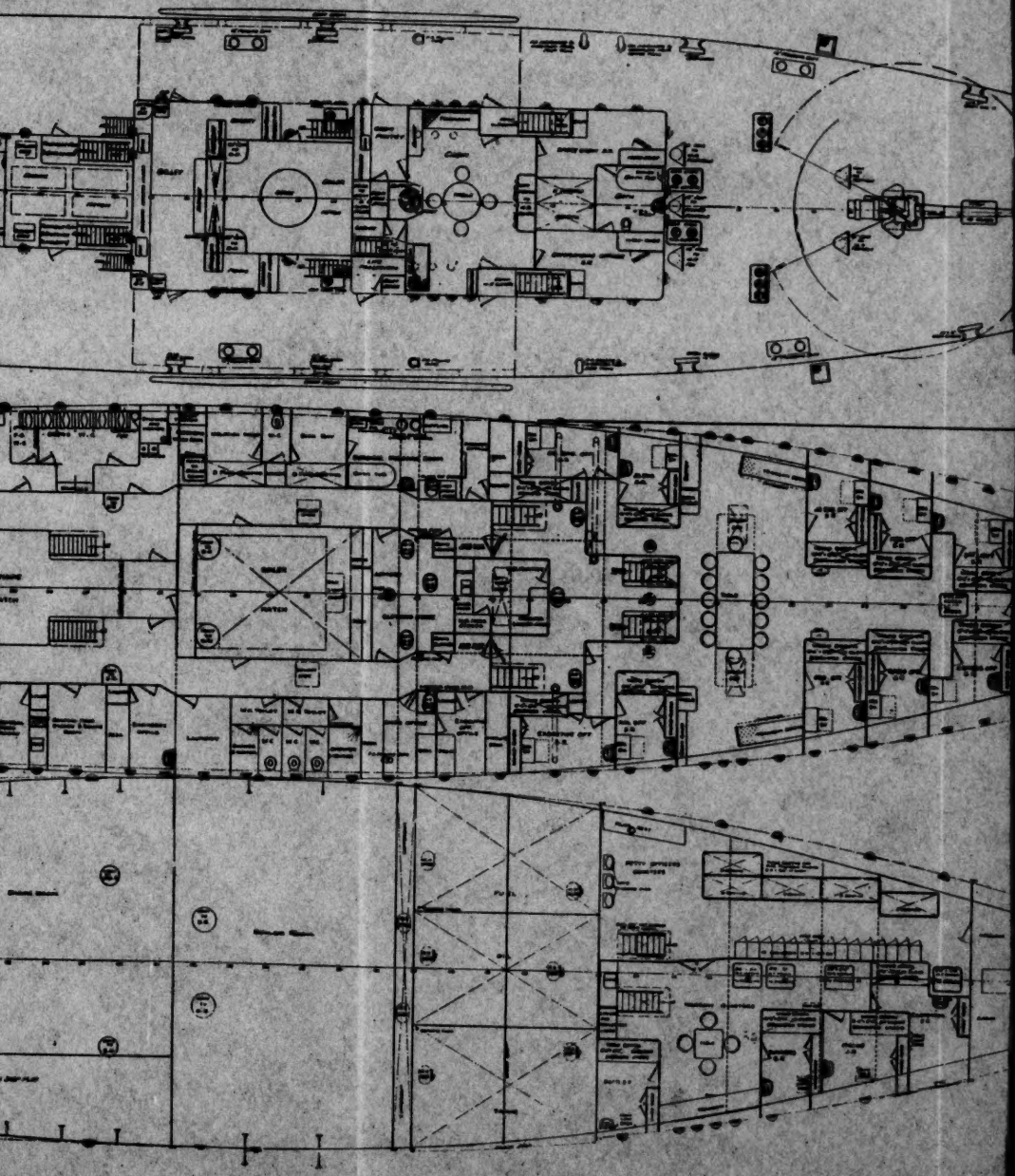
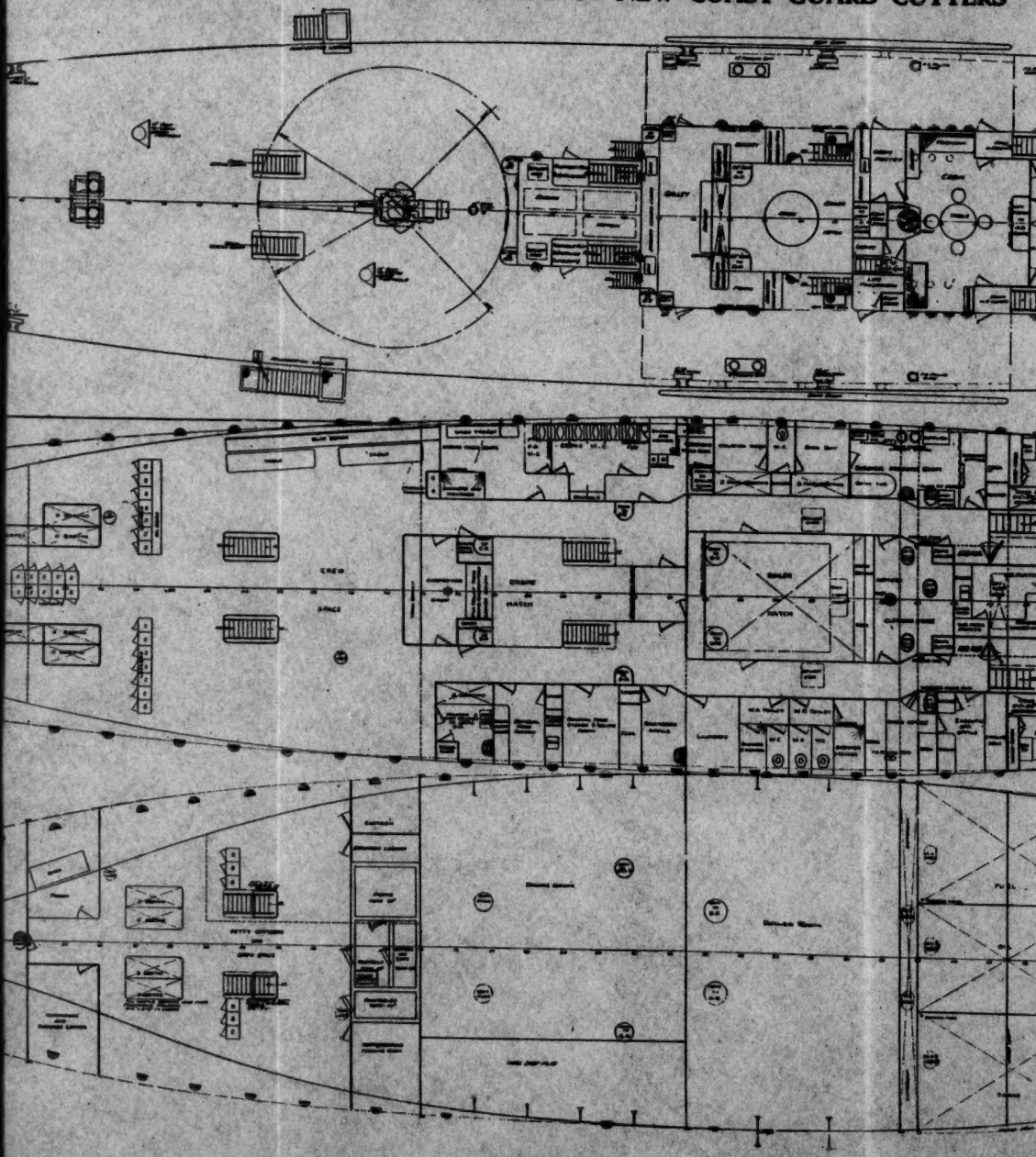


DECK PLANS OF NEW COAST GUARD CUTTERS



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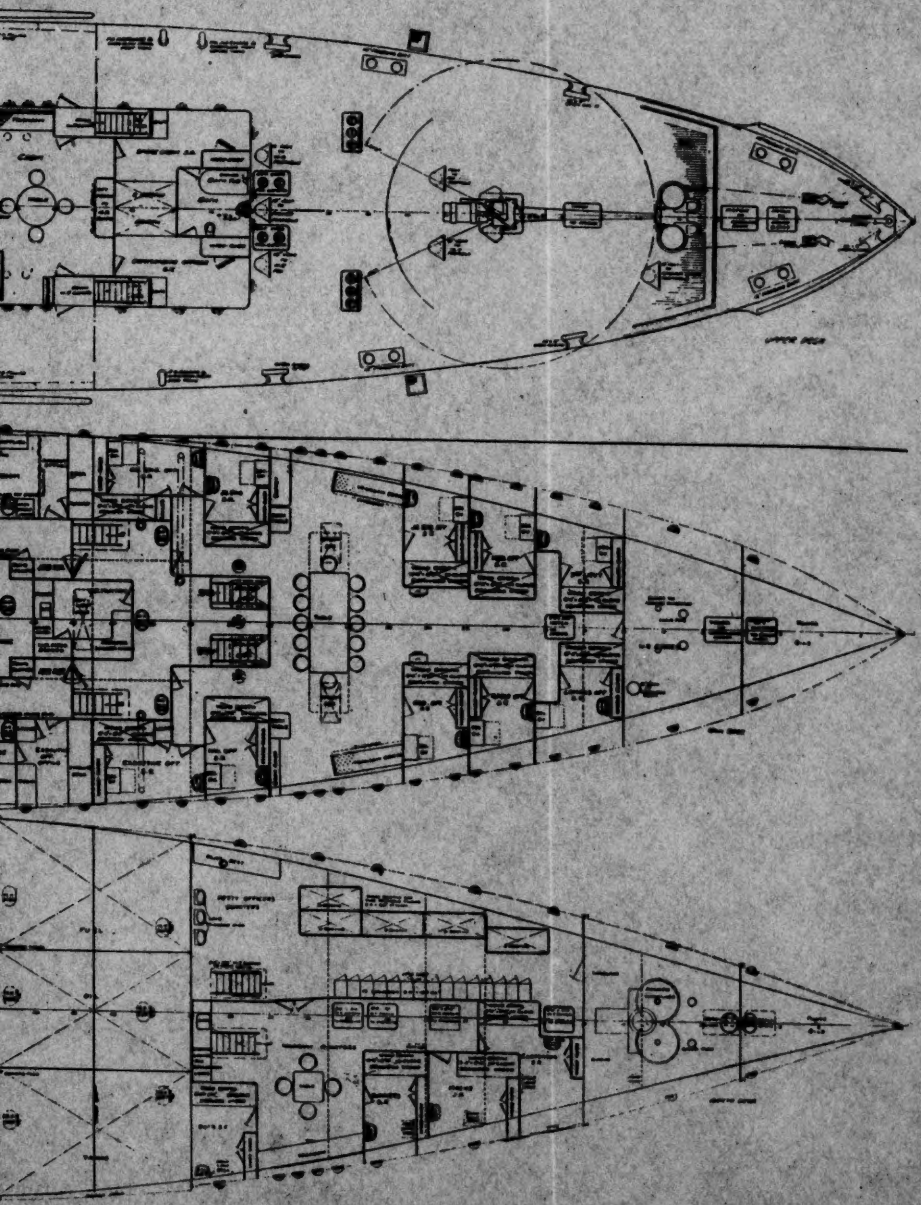


the superstructure deck amidships will be two sets of swinging davits and four other sets of the rotating type will be placed aft. There will be one mast, with the aerial spreader 130 feet above the water-line; and a 26-foot cargo boom having a working capacity of 10,000 pounds. A pair of cast-steel towing bitts, 16 inches in diameter, will be located on the main deck aft.

90,000 GALLONS OF FUEL OIL.

Three fuel-oil tanks will have a net capacity in service of about 30,000 gallons each, a total of 90,000 gallons. Under the boiler-room and the after end of the engine-room, in the double-bottom compartments, will be the reserve feed-water tanks, those below the boiler-room having a capacity of 11,000 gallons, and those below the engine-room, 2,500 gallons; a total of 13,500 gallons. Each of the two fresh-water tanks will have a capacity of 5,250 gallons. Except the portion for reserve feed-water, the double-bottom compartments under the engine-room will not be used.

A steam capstan windlass, with horizontal wildcats, will be capable of hoisting a 4,000-pound anchor and thirty fathoms of chain cable at a rate of six fathoms a minute. The following anchors will be provided: stockless cast-steel bowers, two weighing 4,000 pounds each and one weighing 2,500; stock anchors, one 750-pound stream and one 400-pound kedge. In the upper engine-room will be the steering-engine, which will be capable of putting the rudder from hard over to hard over in twenty seconds while the vessel is moving at full speed ahead, and from hard over to hard over while she is moving at full speed astern. The rudder itself will be of a special design to withstand the shock of possible grounding while the vessel is maneuvering in shoal water, and will have a maximum swing of 42 degrees to each side.

In addition to the usual equipment of voice tubes, an intercommunicating telephone system will be fitted, connecting the chart-room, engine-room, radio-room, cabin, wardroom and executive officer's office.

FIFTH VESSEL A TUG.

The specifications require a dock trial of four consecutive hours at full power; a standardization trial of between eight knots and full speed; and a full-power trial of four hours, the weight of the vessel to be practically that in service condition.

The fifth vessel will be a sea-going tug with reciprocating engines of 1,000 I. H. P.—"Pacific Marine Review."

COMBUSTION MOTORS FOR WARSHIPS.

In a lecture delivered before the "Institution of Petroleum Technologists" on the oil question, Rear Admiral Dumas of the English Navy estimated the yearly production of crude oil at about 75,000,000 tons. This amount by no means meets the needs, therefore every effort must be made to economize in oil. This is of especial importance also to the future development of warship construction, for within a short time the question must be considered as to whether large and costly battleships shall be retained or be replaced by vessels of a smaller submersible type. A type of this kind could be easily designed through the introduction of combustion motors. "Save oil, be economical with it!" he urged upon his hearers. "If for nothing else, we shall need it for future wars, which—take my word for it—will come in spite of all efforts of the host of

geniuses in Paris who declare war on war and wish to make it impossible in the future. In the present conditions of peace lie the elements for a dozen wars. The last war was won from beginning to end by oil—at sea, on land, in the air and in the trenches. The country that has the largest oil reserve will win in the future."

In these statements, very interesting also for Germany and to which one will be able to assent only as regards their clear and practical conception of the case, the Chief Constructor of the British Admiralty, Sir Tennyson d'Eyncourt, has viewed the matter only as it relates to technical problems. He states that he cannot concur in the opinion that the time has come to discard the battleship, but that he would consider it a long step forward if it became possible to perfect the combustion motor and so to increase the power developed in its cylinder that its weight could be reduced proportionately to about that of an airplane motor. It is unfortunately not entirely clear whether the English Chief Constructor had a definite technical problem in mind or at least saw a way practically to attain the step forward indicated by him or whether he was merely expressing an earnest wish born in the minds of naval constructors who regarded the engine practically as a necessary evil and would like to allot to it the smallest possible weight out of the available displacement. The technical paths which seemed the only ones open in the efforts thus far made to adapt the combustion motor to warships, cannot be considered in an effort to attain the reductions in weight suggested above.

The light weight of the airplane motor is possible, for one thing, because of the very high rate of rotation, its manner of working which requires only comparatively small maximum pressure, and finally because of the very great demands upon all structural parts whose lifetime is but short, while long periods of continuous running are required only in exceptional cases. All this fits in very badly with the conditions of warship design. The high rate of rotation would, if we hoped to attain a satisfactory screw efficiency, require a strong transmission system which with the present status of our knowledge could be operated only hydraulically or by electricity; anyone who has ever seen how severe the wear can be, under certain circumstances, resulting from the irregularity of the rotating moment of combustion motors upon even the comparatively slightly stressed gear wheels—for example the steering gear used with Diesel motors and the like—will scarcely be inclined to view the employment of mechanical transmission drive in connection with high-efficiency piston engines as a possibility. Moreover, the high rate of revolution of airplane motors is possible only because comparatively small units with light pistons, etc., are dealt with, and hence the mass effects are but slight. A Diesel motor of ten thousand horsepower, consisting of 6 or 8, in my opinion also 10 cylinders, which could run at the rate of one thousand revolutions per minute, would be so fantastic a design that the very pen of the draughtsman would rebel at being required to record such a plan. It, therefore, seems hopeless to attempt to reduce the weight of such large motors as will normally be required for driving warships, to approximately that of airplane motors by increasing the number of revolutions.

The material stresses, also, which are regarded as permissible in airplane motors cannot be transferred to the motive machinery of ships of the ordinary sort. Many readers will probably still remember what a great mistake was made in trying to use automobile motors for propelling boats, without special adaption; the result of an attempt of this sort to

disregard the difference of the working conditions and thus proceed in an unprofessional manner, was an endless succession of break-downs which very unjustly were charged to the motor and delayed the rapidity of its introduction.

It would be equivalent to learning nothing from such mistakes if one were to admit demands approximating those customary in airship designs in the construction of warship engines in an effort to introduce combustion motors of high efficiency; the sins of the constructor would be visited upon the motor, and there would be no better means of defeating this entirely hopeless course of development than just such a procedure.

And now, what about the manner of working of marine engines? Anyone today undertaking to design a warship with combustion-motor drive —unless he had under consideration a boat or other small craft of comparatively limited efficiency—would scarcely give serious thought to any other type of engine than the Diesel motor. Gas engines, to which considerable thought was given some years ago in England—I will merely mention the projects of Mr. McKechine—do not enter into the question for the reason that they require gas producers with many additional devices which scarcely offers any advantage over the boiler installations of the present day because they are heavy and cumbersome, and because even small leaks in the piping are a danger to the health and even the life of the crew.

A great deal has been written concerning the progress being made with gas and oil turbines, but very little has come to light. They are today far from being sufficiently developed for serious projects to be based upon them; and it is doubtful if in respect to weight they will offer any advantage worth mentioning over the engines of modern warships. A reduction of their weight to that of airplane motors is in any case to be regarded as impossible. Explosion motors, however, which have a lower working pressure than Diesel motors, have not as yet attained an efficiency above 500 horsepower and hence cannot be considered for use in warships. The Diesel motor, therefore, is the only one remaining with which efforts are being made in various countries to develop it to a high efficiency without, however, any details of a reliable nature having become known concerning the results obtained. With the Diesel motor, however, it would be a hopeless undertaking to attempt to attain the weight hoped for by Mr. Tennyson d'Eyncourt.

It, therefore, appears that the enormous "step forward" of which the English chief constructor has spoken is, and is destined to remain, but a devout wish. And yet there is a way by which the end sought may be at least approximately attained within reasonable time, a way which today perhaps would excite ridicule, but which nevertheless leads to possibilities deserving of careful consideration. The Diesel motor, with its high working pressure, drops out of the race, and the explosion motor capable of being manufactured with a much smaller weight takes its place. It is today merely a question of time and necessity before explosion motors will be built, having a high rate of revolution and developing 1,000 horsepower in 6 or 8 working cylinders. For continuous working the total weight of such motors cannot be reduced to that of airplane motors (1.5 kg. per horsepower and below) but may perhaps be brought to about three times this amount, which would keep the mass effect of the moving parts within permissible limits. Zealously pursued experiments are under way, in various countries, striving by different means to attain the same end; namely, to burn heavy oil in explosion motors with efficient and

smoke-free combustion. If these two requirements are met, a large number of motor dynamos can be assembled on board ship in a single electric central. These would have to transfer their current to motors rigidly connected with propeller shafts and located as far aft in the ship as possible, and whose armatures would rotate with the same number of revolutions as are designed for the propellers. Motor dynamos of slight weight are also comparatively small; a whole series of them could be installed in the ship, side by side, separated by bulkheads if need be, and an arrangement of several tiers one above the other, or even a distribution at different points quite widely separated for reasons of safety, would also be possible. Reserves could easily be maintained. If, for example, the ship is required to develop 40,000 horsepower, fifty to fifty-five motors of 1,000 horsepower each—or more if the margin of safety in running demands it—would have to be built in. The motor dynamos kept in reserve, with due regard to working efficiency of transmission, would make it feasible in continuous running, systematically and by series, always to allow a portion of the fast-running engines to rest, to be inspected and overhauled. The adaptation for cruising speed would be perfect, and economy in operation equally good for great and small output of power. All the auxiliary machinery of such a ship would naturally be driven electrically; the current for this purpose would be derived either from the main central, which would have to be correspondingly larger, or be furnished by special motor dynamos.

A project of this kind will probably at first not be looked upon with great favor by naval architects. Aside from many other objections which might be raised against it—the high cost of manufacture would be one essential point—the mere fact that 50 motors of six cylinders each amounting in all to 300 cylinders with pistons, valves, transmission rods, etc., would have to be installed on board would cause cold shivers to run up and down the spine with many. But if we consider the complexity of modern steam turbines with their innumerable blades, each one of which harbors the possibility of a break-down, or if we think of the boiler installations of modern battleships with their pumps and other accessories, the proposed solution will not be found to be altogether so extreme.

It does not come without the purpose of the present article to make a thorough study of the project and to consider all its pros and cons. We merely wish to indicate the path whereby it will be possible, with the means at hand, to approach the great "step forward" that Sir Tennyson d'Eyncourt, of the Institution of Petroleum Technologists, has suggested as a worthy object for our endeavor. Can it be that similar thoughts were in his mind when he spoke?—"Schiffbau."

INTERNAL COMBUSTION ENGINES.

As long ago as 1912 Lord Fisher had come to the conclusion that oil was the naval fuel par excellence, not as a mere substitute for coal in the furnaces of steam-driven ships, but as a prime mover itself. So enamored was he of the internal combustion engine that he at once designed a battleship, which he named the *Nonpareil*, to be propelled by this type of machinery. She was to have had a low freeboard and the minimum of superstructure, sans funnels, masts, etc., reducing the area of target by one-third, and carrying enough oil to take her round the world. While it is very doubtful whether the oil engine of 1912 would have been sufficiently reliable to install in a big battleship, such remarkable progress

has been made since then that there would be no technical difficulty in building a *Nonpareil* today, though her speed might leave something to be desired. It is a complete error to suppose that the British naval authorities are ignoring the possibilities of the marine oil engine. Since the establishment of 1917 of the Admiralty Engineering Laboratory a great deal of experimental work has been carried out, with the result that today Great Britain is little if at all behind Continental manufacturers in respect of internal-combustion engineering.—"The Naval and Military Record," July 21, 1920.

RAPID BRITISH PROGRESS.

One illustration of the British progress in the past three years was given by Eng. Com. C. J. Hawkes in his paper read before the Institution of Naval Architects at Liverpool. He explained that, whereas during the war the Germans had submarine engines developing 300-brake horsepower per cylinder, the standard in this country was only 100 brake horsepower; but in 1918 several British firms were asked to produce designs of single-cylinder experimental engines of from 300 to 400 brake horsepower, and one of these engines is now approaching completion. But, even though this threefold increase in power per cylinder should prove attainable, it does not follow that the oil-engine will forthwith be adopted for the propulsion of capital ships. Our latest battleships, the *Royal Sovereigns*, require 40,000 horsepower to drive them at about 23 knots. If Diesel engines were substituted for the turbine, an installation of equal power would have to consist of at least 134 cylinders in each ship, and the breakdown of a single unit would necessarily lead to a corresponding reduction in speed. This is one of the principal reasons why the appearance of the Diesel-driven battleship may be postponed for several years, or until such time as the power generated in each cylinder has again been largely increased. It should be noted, too, that experience to date with oil-engines in smaller warships has not been altogether encouraging. According to an official statement, the three Dutch gunboats *Brinio*, *Friso*, and *Gruno*, which are propelled by oil motors, have not given satisfaction, and their replacement by steam engines is now under consideration. But against this adverse verdict must be set the fact that several large motor merchant ships have been operating for years with complete success. It is probably well within the truth to say that the marine oil-engine in its present stage of development is at least equal in efficiency to the steam engine for vessels of moderate speed, but that it is not yet sufficiently advanced to compete with the steam turbine for the propulsion of large high-speed ships.—"The Naval and Military Record," July 21, 1920.

MARINE REQUIREMENTS.

How often the phrase "suitable to, or in keeping with, marine requirements" meets the eye! There can also be related numerous examples of types of machines applied to some duty in connection with the propulsion of ships, which, in spite of a very considerable record of successful performance with land installations, did not give the requisite satisfaction at sea and were rejected as unsuitable. The marine market is a

large one, and is continuously being assailed by those responsible for the development of mechanical novelties designed to give increased economy of fuel, with perhaps, in addition, an augmentation of the cargo-carrying capacity of the ship or some other important advantages. It would, therefore, be of considerable interest if these conditions could be stated, analyzed and reduced to simple terms in the light of which any proposal for marine work could be critically examined. Such synthesis would also serve to guide enthusiastic pioneers anxious to capture a share of the marine work, who often themselves have little actual experience of sea-going conditions and by rushing in where others fear to tread, do harm by retarding the progess and application of an innovation possibly having many potentialities. Merit in the long run will undoubtedly win through, but the process of application will certainly be expedited by a careful survey of the particular and unique conditions which must rigidly be met. Naturally, these cannot be specified in an absolute sense. For instance, degree of reliability is a relative quality. It is obvious that for marine work the utmost security in this direction must be attained, and the risks which can be taken whatever the prospective gain, are only a small percentage of those possible with shore plants. The complete stoppage of a land plant at the very worst, rarely causes other than temporary inconvenience and slight pecuniary loss. Quite generally spare machines or alternative methods of obtaining power are available to fill the gap. In any case, the best technical guidance and assistance and unlimited resources can almost immediately be applied to effect a speedy repair. The number and extent of spares kept on the spot is only limited by the question of first cost, but in any case despatch by rail and often by passenger train is available.

The marine case involves other considerations. Firstly, the spares carried are equally limited by considerations of cost. It is further useless to carry spares that cannot readily be shipped into place by the only lifting and handling gear available, generally chain blocks and tackle. No external assistance can be relied upon in the event of a breakdown at sea, the ship's engineers must draw entirely upon their own resources without the assistance of plant other than at best one or two small machine tools, an anvil, and the like. This, however, is not the most important issue. Not only is the safety of the whole ship involved, but life may be endangered by a complete breakdown. The financial loss consequent upon a breakdown at sea is not measured as is quite often the case on land, by the difference in cost between the power generated by the machine which has broken down, and that used to take its place plus the sum of the expenses of the actual replacements, but is represented by the loss of earning capacity, together with the dock dues, etc., plus the cost of replacements often under conditions making for high charges under this heading. Salvage dues, as is well known, are heavy, and many examples of splendid and ingenious performance by marine engineers with a view to their avoidance could be given. Before detailing certain of the more important considerations making for the utmost degree of reliability, some of the other factors which must be taken into account may be stated. Reliability of running continuously is not of greater importance than a complete readiness of the machinery to respond without fail to the demands of maneuvering of the ship in respect of starting, stopping and reversing. Economy of fuel, lightness and capacity for absorbing small space are most valuable assets for marine work, but these advantages are very quickly negatived if reliability is in any way sacrificed.

Marine machinery does not operate on a solid platform. A ship is a flexible structure, and so the question of rigidity of bedplates and alignment of shafts must be viewed from this standpoint. The rolling or pitching of a ship in a heavy seaway makes relatively difficult the lightest duty, so that those parts requiring regular attention should be readily accessible, in view especially of the fact that the average engine-room is sometimes not too well illuminated. Those parts requiring dismantling for examination, or refit, from time to time, should be easily accessible and designed for ready handling with the appliances available. In every case where periodic inspection might give warning of impending trouble, that attention must be facilitated to the utmost. The scantlings of the design must take account of the stresses imposed by the uneven running of an engine with the ship in a heavy seaway, and the impossibility of ensuring always for that degree of dryness and cleanliness possible in land stations should be legislated for. Where spare gear is carried, it must be possible to ship any part into place with the least delay, since time is often a more vital factor afloat than ashore, as when a ship is stopped off a lee shore. A marine engine is neither a constant speed nor a constant load machine. Its speed varies with many conditions—the loading of the ship, the weather, whether in a sea way or in smooth water, against head, beam or following winds, and again, when towing another vessel. All these factors influence the ratio of power and speed of revolution and call for a high factor of safety, the utmost accessibility and handiness.

This subject of marine requirements has only been treated very briefly, but sufficient has been said to show why, for instance, the relatively uneconomical reciprocating steam engine for so long has held, and continues to hold, the marine field. It fulfills all the particular conditions of marine requirements to a degree not yet surpassed by any other prime mover, and when challenging its position, success will be more certain the greater the attention that is paid to the essential features, a number of which have been enumerated.

Surprise has often been expressed that the water-tube boiler makes such slow headway in the mercantile marine. The old cylindrical Scotch type remains the standard. The large quantity of water under pressure and in circulation, and the relatively large volume of steam contained in the steam space with this standard type gives virtues in security of operation under all conditions at sea, and enables, when maneuvering, for instance, the fluctuating demands in regard to power and speed of engine, to be immediately met. Again the record of satisfactory performance with the Scotch cylindrical steam generator is an argument of the utmost potency where marine engineers are concerned. Many schemes to overcome the prejudice towards water-tube boilers have been propounded, and for certain duties, where their quick steam raising properties, light weight and small space occupied are important considerations, they will be increasingly applied in the future. Only those types of water-tube generators specially designed for marine work, however, can hope to succeed in the final issue. No less important than the main steam engines and the boilers, are the many auxiliaries upon which they depend, and it is perhaps in this field particularly that innovations are constantly being put upon the market. The immediate success of certain recent devices and accessories goes to prove the willingness of the marine superintendent engineer of today, to try out novelties, provided it can be proved and represented that they fulfill the essential tenets of marine requirements.—"Engineering."

NAVAL ENGINEERS.

Higher Posts to Be Opened in the Service.
Admiralty's New Scheme.

In the statement of the First Lord of the Admiralty explanatory of the Navy Estimates, 1920-21, it was pointed out that final separation between the officers of the deck and engineering sides of the naval service was necessary. These words were used: "There is a definite distinction both as regards knowledge and capabilities between those who are to be trained in the science of naval war, and strategical and tactical methods of fighting and those who are to deal with the upkeep and maintenance of engineering and mechanical appliances which are necessitated by the complex machinery and weapons of modern war. Each side requires a special study, and for this reason final separation of the branches is essential." At the same time, the importance of close co-operation between the deck and engineering branches was emphasized. In a statement issued by the Secretary of the Admiralty on Friday, it is pointed out that separation being accepted, the prospects of each branch should be such as to maintain high efficiency in the personnel composing the branch. So far as the deck side is concerned this is allowed for by the prospects of high command opened up, but on the engineering side it cannot be said that this is fully the case, and, with the exception of the office of the engineer-in-chief and certain technical appointments, there are comparatively few higher posts. There is a danger, therefore, that under existing conditions the engineering side may fail to attract its due proportions of officers of ability, and the service will suffer in efficiency accordingly.

Since the statement of the First Lord this matter has received consideration, and the steps outlined below have been taken:—

ENGINEER-IN-CHIEF.

The engineer-in-chief at the head of the naval engineering profession has up to the present been under the Third Sea Lord and Controller. His primary responsibility was design and supply, his department being organized to meet the requirements of design and supply. Whilst retaining his responsibility to the Controller as above, it has been decided that in future the engineer-in-chief shall be responsible to the Chief of the Naval Staff for advice on all matters in connection with naval engineering policy. He will work in close touch with the Naval Staff, being thus conversant with the trend of naval policy and being in a position to frame his engineering plans to meet the requirements of policy. It has further been decided that the engineer-in-chief shall be the Board's principal adviser upon all questions relating to the instruction and training of engineering personnel, he being for this work directly responsible to the Board through the Second Sea Lord. Thus the office of the engineer-in-chief as head of the engineering side of the naval profession will have extended scope, and the department of the engineer-in-chief will offer posts of the highest administrative importance and responsibility for senior engineer officers.

ADMIRAL—SUPERINTENDENTS.

After the engineer-in-chief, the most important positions in the naval service of a technical and administrative order are the posts of admirals-superintendent, responsible for the administration of H.M. Dockyards. Hitherto only officers from the deck branch have been eligible for this

service, but it is intended that in the future, when officers of the common entry or special entry systems, who have joined the engineering branch, have attained high rank, that these officers also should be considered with deck officers for these positions. Should the admiral-superintendent be such an officer, the principle would be adhered to that he would not be eligible to command the port, since command of the port in time of war deals with operations, the province of the deck officer.

REVERSION TO DECK DUTIES.

The Board have also had under consideration the rule under which lieutenants who have had one year's experience as watchkeepers before specializing in engineering are allowed to retain the right of military command until between 7½—9 years' seniority as lieutenants, when they must decide to remain at engineering or revert to deck duties. The duties of lieutenant (E) are becoming more and more exacting, and it is considered that in the future it will be impracticable to give effect to reversion to deck duties after a number of years spent on engineering duties. It has consequently been decided that the option of reversion to deck duties should now be withdrawn altogether from officers who volunteer for engineering duties in the future. Officers who have already volunteered will remain under the existing rules.

FURTHER POSITIONS.

To investigate the possibilities of carrying further the separation of the work of strategy and tactics from that of upkeep and maintenance, a committee is now sitting on the question of transferring the responsibility for upkeep and maintenance of electrical machinery in H.M. ships from the torpedo department on the deck side to the engineering department, and thus, apart from other considerations, opening up further positions, both in the junior and higher ranks, to officers who have chosen engineering duties as their career in the Navy. A decision will be promulgated as soon as possible after the report of the committee has been received and considered.—"The Naval and Military Record," July 21, 1920.

THE COMMON ENTRY SYSTEM.

"In reckoning up the leading factors that brought us victory in the late naval war I would place engineering efficiency among the foremost. Deck officers learned to place implicit reliance in the engineers, and never once did they let us down. If I were asked to explain this high standard of perfection in the engine-room, I would attribute it mainly to the increased sense of responsibility which the engineering branch has gained since the introduction of the common entry system. Apart from its effect on technical efficiency, that system has proved invaluable in bringing officers of the deck and engineering branches closer together and fostering the spirit of reciprocal support which is the real key to victory." The foregoing words, uttered recently by a flag-officer who held important commands throughout the war, have a special interest in view of the new development in Admiralty policy with regard to the naval engineering branch. As we observed last week, the latest modification does not affect the basic principle of common entry, and we do not accept the view, held in some quarters, that it represents the thin end of a wedge destined eventually to split the Selborne scheme asunder by reviving the system of separate entry for engineers that prevailed up to 1903. Were

such an intention to be mooted we should oppose it as being gravely detrimental to the interests of the service. The common entry method has triumphantly withstood the supreme test—that of a prolonged and most exacting war—and the case for its perpetuation is unassailable. Moreover, the present Board of Admiralty have publicly declared their confidence in the merits of the existing arrangement. When announcing the contemplated division between the deck and engineer officer after each has definitely chosen his sphere of specialization they pointed out that each branch must understand and sympathize with the requirements of the other. "In the exercise of strategy and tactics it is necessary that there should be full understanding of the engineering and mechanical possibilities and difficulties, and how such difficulties can be overcome. On the engineering side it is equally necessary that there should be an understanding of the requirements of the strategist and tactician, in order that, so far as practicable, his requirements may be met and perhaps anticipated." It was added that "by means of the common entry system and training under a similar system until about the age of 20, when the rank of commissioned officer is reached, it is believed that this sympathy and understanding between deck and engineer officers will be fully and completely obtained."

It cannot too often be repeated that the outstanding merit of the Selborne scheme was its abolition of the old class distinctions that formerly kept the two branches apart. This gulf existed until well within the present century, and a great many officers now on the active list remember the penalties that were visited upon a junior who so far forgot himself as to consort with his engineer shipmates more closely than service routine required. Those bad old days are gone, as every rational person hopes, forever. The only danger of their recurring is that the engineer branch may not offer sufficient prospects to keen and ambitious officers past a certain stage of promotion, and it was with a view to averting that peril that the Admiralty lately decided to enlarge the number of responsible appointments open to engineer officers afloat and ashore. Should this expedient fail to attract the requisite proportion of officers to the engineering branch some alternative scheme will have to be worked out. Above all things, however, it is important to preserve the system of common entry, which is the one sure safeguard against the restoration of the invidious caste spirit, which, in our judgment, would be most injurious to naval efficiency.

If further evidence is desired on this point it will be found in the record of the German Fleet during the war. In that service the engineer officer was regarded and treated as an inferior, both professionally and socially, and care was taken to see that only applicants of a humble social grade were accepted for the branch. This snobbery was carried to such an extreme that only two years before the war a German engineer officer who took his wife to call upon an executive officer serving in the same ship was severely disciplined for his "presumption." In these circumstances it is not surprising that the engineering efficiency of the German Fleet during the war left a good deal to be desired. Admiral von Pohl's correspondence is full of complaints on this head. There were occasions when all the best ships of the High Sea Fleet were disabled by engine-room defects, and the position had not improved by the time Scheer took over command, for his book records numberless instances of the same trouble. It was exceedingly rare for any German ship to attain her trial speed when in action, whereas in our service nearly every ship bettered its trial performance, and notorious lame ducks steamed with the best when a special effort was needed.—"The Naval and Military Record," August 4, 1920.

"STILL" AND "SULZER" MARINE ENGINES.

Comparative Trials of "Still" and "Sulzer" Engines Under Actual Working Conditions on Board Ship.*

By Mr. William Denny.

In the year 1913, Messrs. William Denny and Brothers took out a license from the firm of Sulzer Brothers, Winterthur, for their special type of oil engines. To obtain experience in the manufacture of such engines, they arranged to proceed with small twin-screw engines of about 250 I.H.P., in all, and to build a hull in which these engines would be thoroughly tested—both the hull and the power of the engines arranged for corresponded with a standard type of light draught passenger and cargo steamer, of which a number had been built for service in the rivers of India and Burmah. These vessels are 100 feet long, 23 feet 6 inches beam, and 7 feet 6 inches deep, and have an approximate speed of 10 knots with 250 I.H.P. When war broke out the hull and engines for this experiment were well advanced, but under "control" conditions the work on them was stopped to make way for the pressing requirements of the Government.

For some time before the war the firm had been interested in the "Still" engine; fairly early in the war period it was arranged, with the consent of the Admiralty, that an experimental Still installation, to correspond with the hull already mentioned, should be proceeded with, being twin-screw engines of, in all, 250 I.H.P., or thereby. This arrangement was carried out and the vessel with the Still engine was exhaustively tried.

On the conclusion of the war it was decided to complete the original set of Sulzer engines and fit them to the same hull—the Still installation, so far as necessary, being, of course, removed from the vessel. This experiment also was duly carried out and the results with both types of engines are given later.

In carrying out these comparative trials everything possible was done to ensure that the results in all respects would be reliable—the same oil was used, the same propellers, the same draught, the vessel was run on the mile to check the speed in terms of revolutions, the oil consumption trials were repeated several times, and during each trial were checked at stated time intervals, and it is considered that the results as given may be regarded as reliable.

The Sulzer type of oil engine is well known and the Still system has been fully described in a paper read by Captain F. E. D. Acland before the Royal Society of Arts on May 26, 1919, but, for the information of those who have not yet read that paper, it may be stated briefly that the Still type of engine is a combination of the steam and of the internal-combustion engine, steam acting on one side of the piston, while oil combustion takes place on the other side, within the same cylinder. A small boiler is part of the installation, from which the steam, generated by burning oil in the boiler in the usual way, is employed as the starting agent for the engine; the boiler also acts as a receiver for the steam derived from the waste heat of the exhaust gases of the internal-combustion part of the engine. The feed water is circulated by a pump drawing from the bottom of the boiler and discharging through the tubes of a generator, which is heated by the exhaust gases of the engine passing round the tubes; from thence the water passes to the cylinder jackets of the engine, where it is used as the cooling agent, thus gaining more heat, and there-

* Paper read before the Institution of Naval Architects, July 8, 1920.

after returns to the boiler in the form of steam and water. The steam thus generated is used in the steam end of the cylinder, and adds to the power of the engine as a whole. The exhaust gases pass to the atmosphere on leaving the generator.

When the engine is running normally, *i.e.*, under "waste-heat" conditions, no fuel is burned in the boiler, the steam available being generated solely from the heat in the exhaust gases and from the heat transferred through the cylinder liner to the jacket water. The engine may be run at a considerable overload by augmenting the supply of steam through burning fuel in the boiler. Owing to the high temperature of the cylinder jacket cooling water (*i.e.*, boiler water), the compression pressure in the cylinder necessary for the ignition of the fuel is considerably lower than is the case in ordinary Diesel engine practice. The cycle of the steam portion of the engine is just as in ordinary steam practice, an air and circulating pump, condenser, boiler feed pump, &c., forming part of the installation.*

The Sulzer engines in question have cylinders approximately 8½-inch diameter by 13¾-inch stroke—four cylinders to each engine—and are of the two-cycle type. The Still engines have also four cylinders per set, 7¼-inch diameter and 15-inch stroke, fitted with a boiler of the Yarrow type—they are of the opposed piston type and two-cycle.

The Still engines were designed with a view to their powers of maneuvering being beyond question. It was suggested that a separate high-pressure cylinder might be fitted, the other cylinders being the second unit of the ordinary compound engine. By this means some economy might have been effected, but this complication was decided against. It may be added, while it has nothing to do with the question of relative economy of the engines, that the Still engines were arranged to run astern under steam only. Owing to this the boiler was larger than would be necessary in an engine arranged for astern working with oil also.

The Sulzer engines on the other hand were made to the patentee's design of 1913. Improvements have been made since then, and it is possible that some of these improvements may tend towards greater economy. It will be observed that the Sulzer engine cylinder capacity is considerably larger than that of the Still engine, which has an effect on the varying relative consumptions at the different numbers of revolutions. In the Still engine the maximum revolutions without overloading and without the use of oil in boiler were about 240.

A representative of each patentee was present at the trials of his own system, and was satisfied that the trials had been carried out in an approved manner. The trials were continued until these representatives were unable to suggest any modifications by which better results might be obtained. The oil used on the trials was shale 0·85 specific gravity. The maneuvering of both types of engines was quite satisfactory. From ahead to astern the time was about 5 seconds, and in this respect the Still engine had a slight advantage. During the trials, as shown on Fig. 4, the Still engine worked entirely under waste heat conditions, *i.e.*, no oil was burned in the boiler.

It had been suggested that, in the case of the Still engine, oil from the cylinders might find its way to the boiler and have a dangerous effect on it. With this possibility in view the boiler was frequently examined during the trials with the Still engine and also at their termination and there

* As the experimental engines in question were started, and maneuvered astern, under steam, and, as in this case, the solid oil injection principle was adopted, neither storage of compressed air nor compressor was necessary or provided.

Fig.1.

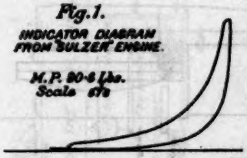


Fig.2.

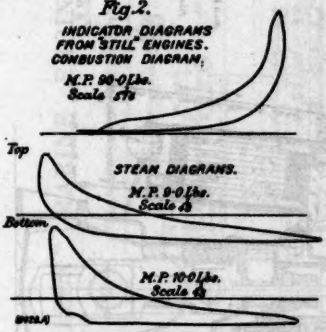


Fig.3. FUEL SHALE OIL. SPECIFIC GRAVITY (·86) AT 60°F. CALORIFIC VALUE ABOUT 19,000 B.T.U. (GROSS).

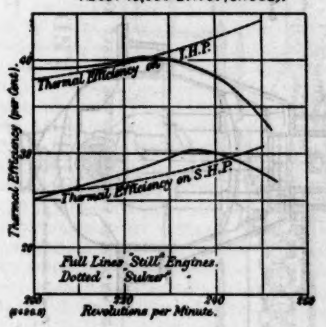


Fig.4.

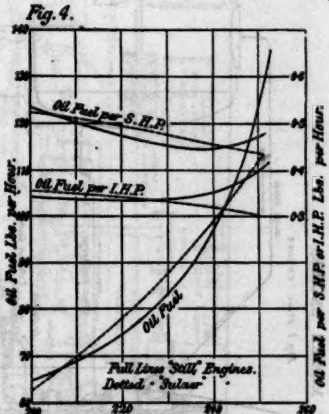
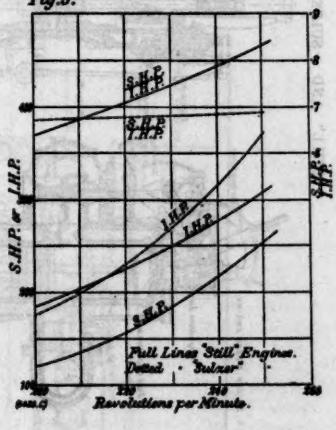
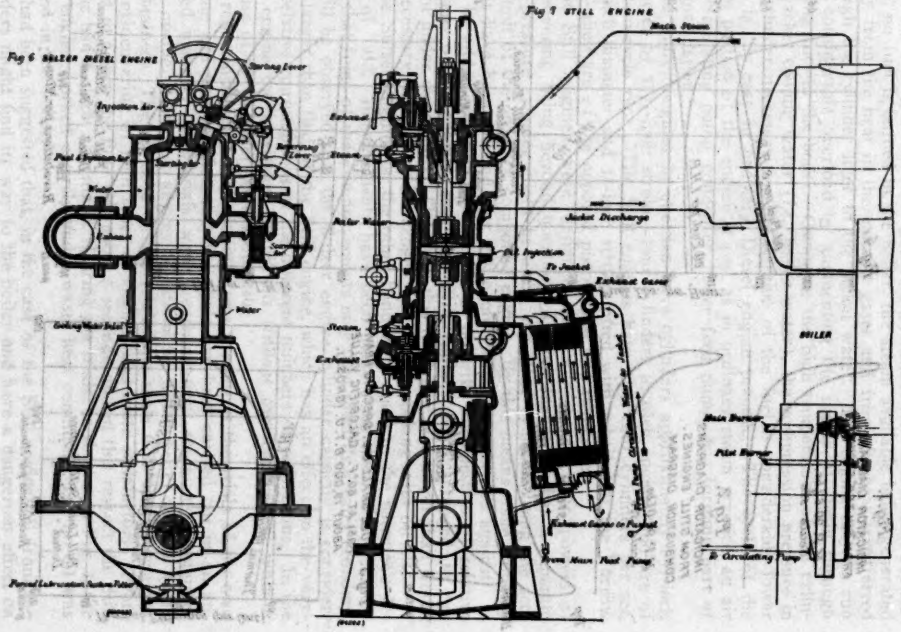

Oil Fuel per S.H.P.
Oil Fuel per I.H.P.
Oil Fuel
Oil Fuel Lbs. per Hour.
Oil Fuel per S.H.P. or I.H.P. Lbs. per Hour.
Full Lines "Still" Engines.
Dotted · "Sulzer" ·
Revolutions per Minute.

Fig.5.



"STILL" AND "SULZER" MARINE ENGINES.

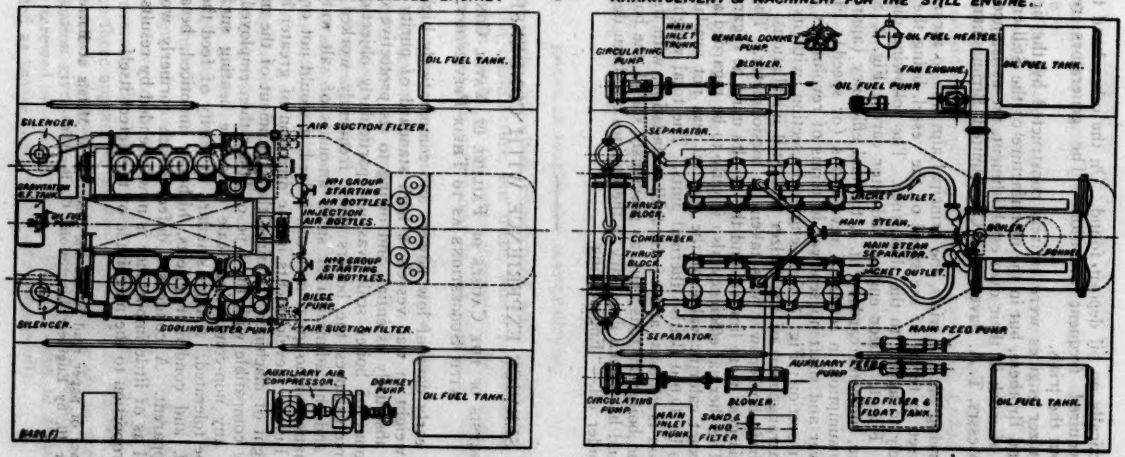


"STILL" AND "SULZER" MARINE ENGINES.

ARRANGEMENT OF MACHINERY FOR THE SULZER DIESEL ENGINE.

Fig.8.

ARRANGEMENT OF MACHINERY FOR THE STILL ENGINE.



was practically no oil deposit found. On the other hand the feed water filters required frequent attention. The generators remained clean throughout the trials.

The Sulzer engines were entirely constructed by the firm of William Denny and Brothers, but in the manufacture of the Still engines owing to pressure of work in their own establishment, the assistance and co-operation of Messrs. T. A. Savery and Co., Limited, Birmingham, was arranged for.

In carrying out the trials, the principal aim was to ascertain accurately the oil used in terms of the speed of the vessel, being the point of view most likely to appeal to the shipowner. The following diagrams are appended: Fig. 1, Sulzer engine, indicator cards; Fig. 2, Still engine, oil and steam, indicator cards; Fig. 3, thermal efficiency (approximate); Fig. 4, oil consumption in terms of revolutions (or speed); Fig. 5, indicated horsepower and shaft horsepower in terms of revolutions. Fig. 6, Sulzer engine in section; Fig. 7, Still engine in section, with its boiler; Fig. 8, general arrangement of the Sulzer and Still installations.

The shaft horsepower was taken by torsionmeter. The facilities for fitting this gear were limited, and the results must be regarded as approximate. The thermal efficiency also is only to be regarded as approximate, as the exact calorific value of the fuel oil was not available; it was assumed to be 19,000 British thermal units. The total weight of the Sulzer installation is 25 tons, and of the Still installation, with its special accessories and boiler, 29 tons; but, as previously stated, the boiler was larger than would have been necessary if the engines had been designed to work astern under oil.—"Engineering."

SERVICE EXPERIENCE WITH CONDENSERS.*

An Analysis of the Causes of Failure of Naval Condenser Tubes, with Suggestions as to Their Prevention.

In the early days of low powers and comparatively high ratio of machinery weight in war vessels, a high standard of purity of feed-water was not absolutely essential, and owing to its protective qualities a certain amount of boiler scale was not particularly objectionable. Under these circumstances the boilers were frequently worked with a slight density, and the admission of small amounts of salt water to the feed was a matter of no great moment, indeed, it would not ordinarily be detected. Further developments in the direction of greater horsepower per unit weight of machinery required the attainment of the maximum boiler efficiency compatible with the type of boiler then employed, and the presence of any non-conducting scale upon the heating surfaces could no longer be tolerated. A high standard of purity of feed therefore became essential, and condenser effects, hitherto unnoticed, became more and more apparent. A condenser defect which formerly would have been regarded as of little importance is now attended by results which are out of all proportion to the magnitude of the defect itself.

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* Abstract of paper read before the Institute of Metals at Barrow-in-Furness, on September 16, by Engineer Lieut.-Com. G. B. Allen.

EFFECTS OF SMALL PERFORATIONS.

Among the immediate results following upon such a defect as a small perforation are:—

(*a*) A rise in the density of the boiler water followed by priming (*i.e.*, the passage of water with the steam through the system), with consequent possible damage to fast-running reciprocating auxiliaries, and undue wear (erosion) of turbine nozzles in modern vessels; and unless the evaporation is considerably eased and the engines either slowed down or stopped, the mechanical damage caused by the water passed over may be very considerable.

(*b*) The deposition of scale upon the heating surfaces.

(*c*) The commencement of serious corrosive action in the system, including both boilers and turbines, the first-named being particularly severe in the highly forced boilers of the present day.

It is on these grounds, both of reliability and durability, that the importance of maintaining a pure "feed" rests.

Fortunately the proportion of defective tubes compared with the number of tubes on service is extremely low and is not greater than 50 in 1,000,000 per annum; but if it be realized that in a large vessel fitted with some 48,000 tubes of a total length approximating to 115 miles, such a small defect as 1-16-inch diameter hole or one cracked tube may render the vessel unmanageable in a moment of great stress, it will be evident that it is a matter of great importance to secure immunity from such defects, and, moreover, one which requires considerable investigation and joint co-operation between the manufacturer, the metallurgist and the user.

ERRORS IN DESIGN AND MANUFACTURE.

Many of the early difficulties experienced were found to be due to faulty design and manufacture, but these, which concerned accuracy of fitting rather than faults in the tubes themselves, have been gradually eliminated. Defects of this nature may be summarized as follows:—

1. Insufficient support of tubes between the tube plates.
2. Holes in diaphragm plates too large.
3. Holes in tube plates too large or too small.
4. Unsuitable packing.
5. Slackness of furrules in tube plates.
6. Steam or drain orifices unsuitably placed, allowing steam and hot water, sometimes contaminated with oils, to impinge on certain tubes.

Insufficient support led to undue vibration of the tubes, and although this has been largely rectified by the provision of suitable and unequally spaced diaphragm plates, and by limiting the diameters of the tubes and the holes through which they pass, a certain clearance must of necessity be allowed, and the effect of vibration, more especially in high-speed vessels, cannot be ignored. Since the adoption of limiting clearances, defects of this character have to all intents and purposes been eliminated.

Opinions concerning the suitability of packing materials vary, and outside the service there appears to be little uniformity of practice. Experience in naval vessels shows that the linen gromet made to present Admiralty specification gives every satisfaction, and with ferrules and their stuffing boxes screwed to correct gauge, difficulties due to gland leakage may be regarded as having been coped with successfully.

CAUSES OF GENERAL CORROSION.

Investigations into the general problem of the nature of the underlying causes of corrosion within the alloy itself have resulted in various theories, none of which have as yet met with general acceptance, and in the present stage the most we are able to do is to endeavor to trace each defect to its immediate observable source. In many cases this is possible and is a fairly simple matter; but in others, such as may be covered by the description "general corrosion," considerable difficulty may be experienced.

The information available at the Admiralty is derived from reports forwarded by ships as failures occur. From examination of reports received since the cessation of hostilities, the following statement has been deduced to show the present causes of failure in the proportion in which they have occurred:—

	Per cent.	
(*a*) Deterioration at inlet ends	18	of total failures.
(*b*) Perforation due to local pitting	14·8	" "
(*c*) Perforation due to obstruction	14·8	" "
(*d*) Perforation due to steam impingement	5·4	" "
(*e*) Crushed ends	5·4	" "
(*f*) Splitting	10·8	" "
(*g*) Perforation due to contaminated circulating water	1·0	" "
(*h*) General corrosion	29·8	" "

The large proportion of failures due to deterioration at the inlet ends of the tubes is noteworthy. Generally speaking, there is a marked thinning away at the ends of the tubes (not infrequently accompanied by wear of ferrules) culminating in perforation at from 1 inch to 3 inches from the end.

FAILURE AT TUBE ENDS.

In many cases where the greatest intensity of the deterioration occurs at the upper inside surface of the tube the presence of air has been held to be the chief contributory factor, and under such circumstances the provision of air-releasing devices at the highest point of the circulating water system has proved of marked benefit. However, with all such mechanical precautions the evacuation (before entry to the tubes) of air which is necessarily in suspension in the circulating water is only partial. The sharp edges, both of ferrule and tube, assisted to some extent by the possibility that the tube and ferrule may not always lie perfectly concentrically, tend to break the flow of water and to form pockets of an unstable nature where air may be reasonably expected to accumulate.

This type of defect has been particularly noticeable in vessels serving in shallow waters containing a considerable proportion of solid matter, *e.g.*, sand, chalk, &c., and this, together with the comparatively high-water velocity through the tubes, points to the influence of erosion or the abrasive action of gritty particles, as being of considerable importance. It appears that investigations with regard to the elimination of this type of defect must take the lines of endeavoring to obtain a metal whose surface is better able to withstand this abrasive action.

Whereas in the cases of tube-end deterioration the number of tubes affected in any condenser (apart from those which actually fail) may be

considerable, cases of local pitting are rarely evident in more than one or two tubes in the condenser concerned, and when once a failure has occurred and the tube is plugged or replaced, little further trouble is experienced. In these cases perforation occurs at isolated spots, and the failure has been generally considered to be due to some local defect, *e.g.*, a spill or lamination. The elimination of defects of this character is entirely a question of the manufacture of the mechanically perfect tube, which desirable result can only be attained by the drawing down of a mechanically perfect cast shell. The practice of turning and boring each shell, even if regarded as merely for purposes of exploration of the metal immediately beneath the surface skins, has a considerable safe-guarding effect toward the reduction in the number of such surface irregularities as may be discovered on sighting. Perforations, the cause of which has been directly traced to obstructions, were particularly prevalent in coal-burning ships where the ashes were discharged beneath the waterline.

The recorded cases where failure has occurred through the impingement of steam and water directly on a limited area of the outer surface of certain tubes are few. Such failures should not occur, provided that orifices are suitably placed and baffled.

FAILURES DUE TO CRUSHING.

The proportionate number of failures due to crushing is small, and these may be regarded as isolated cases. In no case has it been established that over-tightening of screwed glands has been resorted to, and the fact that crushing sometimes does occur, serves to emphasize the importance of the tubes being sufficiently hard to stand a reasonable margin of pressure due to tightening up above that absolutely necessary to secure watertightness, though it may be remarked that crushing is sometimes observed as a natural result of the weakening of tubes which have been attacked internally by corrosion of a general nature.

There is some divergence of opinion as concerning the most desirable degree of purity of the 70 : 29 : 1 alloy, but investigation has shown that a large proportion of the tubes which have failed from splitting have been manufactured from materials of a lower standard of purity than that required by the Admiralty specification.

Apart from the question of purity of constituents the internal condition of stress in the finished tube must have considerable bearing on the liability to season cracking and splitting.

The case in which failure has been directly ascribed to the use of unsatisfactory circulating water is exceptional, but it certainly gives weight to a widely held opinion that the conditions under which many condensers are worked in the early stages of their life (*e.g.*, in comparatively stagnant fitting-out basins contaminated by various kinds of refuse) are conceivably of importance as a primary cause of tube decay.

The proportionate number of recorded failures due to general corrosion does not adequately express the importance of this class, these being cases of actual failure only, *i.e.*, general corrosion culminating in perforation; whereas the great majority of cases in which general corrosion is present are not recorded, and it is the possibility of failure at an unknown moment which gives this matter so serious an aspect. Leakage from electric circuits has been put forward as being a contributory cause of corrosion, but though no evidence of a positive character has been obtained in support of this contention, it has been observed that failures have occurred shortly after the discovery of "earths," and it is probable that the effect, if any, is one of acceleration rather than a primary cause.

The general problem of corrosion of condenser tubes may be conveniently regarded from four different standpoints:—

1. The arrest or prevention of corrosion in condensers as at present constructed.
2. The treatment of tubes of accepted composition.
3. The general design of condensers.
4. The utilization of more suitable alloys than those at present in use.

The provision of steel protector plates and cast-iron water-ends has proved satisfactory in checking the rate of deterioration provided that good connections are secured, but at the same time considerable wear of the cast-iron ends takes place, and this wear, if excessive, is a very undesirable feature. The present Admiralty practice is to make the tubes and tube plates of as nearly the same composition as is practicable and to secure steel slabs direct to the tube plates, but from the foregoing remarks it cannot be said that this practice is entirely effective.

The Cumberland process has been fitted in certain vessels, but beyond the fact that it has been found that this process has not arrested decay where such decay has been in evidence before the process has been installed, the experience gained has not been sufficient to allow of any reliable conclusions being drawn.

With regard to the treatment of working tubes, the Admiralty (acting on a well-known and successful practice of coating corroded copper pipes with a film of pitch and marine glue) have experimented with resistant varnishes. In the first vessel treated, although a certain degree of protection was obtained, it was found that probably as a result of the erosive action of the water (but possibly on account of the difficulty of forming a film of even thickness and of satisfactory drying), the varnish became washed away in places, thus exposing portions of the bare metallic surface to the action of the water. Experience with a second vessel has not been extensive, but it is understood that general corrosion which formerly resulted in comparatively frequent failures has been entirely arrested. In these cases the varnish has been applied to the tubes "in place," and dried by the admission of steam to the condenser. The protective value of an oxide film has been suggested by a former report of the Corrosion Committee, and the Admiralty have under observation a vessel fitted with tubes on which such a film has been formed, unfortunately this vessel has done very little steaming and no useful data have as yet been obtained.

In regard to the elimination of failures caused by surface defects, *e.g.*, spills, a vessel has been fitted with compound tubes made on the lines suggested by Sir Charles Parsons,* but here, again, owing to post-war conditions it has not been possible to obtain any conclusive results.

EFFECT OF CONDENSER DESIGN.

The general design of condensers has been found to be closely connected with tube defects, or rather with the acceleration of deterioration, and in particular in regard to certain designs where the whole of the tubes are not drowned. In these designs a few of the upper rows of tubes which are situated above the waterline have been observed to be particularly prone to corrosive action, and consequent upon the general thinning this action is not infrequently accompanied by "end crushing."

The Admiralty have from time to time experimented with tubes of vari-

* Journal of the Institute of Metals, 1911, vol. vi., p. 305.

ous compositions, but experience to date has shown that the tubes made to Admiralty specifications have proved the most satisfactory under the varying conditions imposed by naval service. With every precaution taken during manufacture and with the adoption of any known preventive or protective process it must be admitted that freedom from deterioration cannot be guaranteed. and it appears that complete immunity, or at least a guaranteed life, can only be obtained by the employment of an alloy other than a simple brass.—"Shipbuilding and Shipping Record."

LIGHT CRUISER DESIGN.

With the recent launch of the *Emerald* on the Tyne, all the light cruisers ordered for the Navy during the war have now been put afloat, with the one exception of the *Effingham* at Portsmouth. The *Emerald*, and her sister-ship the *Enterprise*, now at Devonport Dockyard awaiting completion, belong to a class which did not appear in any of the lists of ships built during the war, and which it is thought had been abandoned after the armistice. The "E" type is, however, so much superior to the eight vessels of the "D" class that from the constructive point of view it is a good thing that two ships of the type should have been spared. The outstanding feature of the *Emerald* will be her speed—from 32 to 33 knots—which will make her quite the fastest cruiser ever designed for our Navy, the previous limit of design being thirty knots. At this high rate, moreover, she will carry seven 6-inch guns, or one more than in the "D" class, and will be infinitely superior in armament to the *Arethusa*, with her mixed battery of two 6-inch and six 4-inch guns. As an engineering proposition the design of the *Emerald* must have presented many difficulties. Her tremendous drive of 80,000 horsepower exceeds that of all our battleships, and also of the battle-cruisor *Lion;* in fact, only the later battle-cruisers in the British, American and Japanese Navies have a higher engine-power. For many reasons the design is most interesting, and although progress in construction seems likely to be slow, owing to the need of economy, the trials of such a vessel will be awaited with much keenness.—"Army and Navy Gazette," July 10, 1920.

IS NAVAL DESIGN IN THE FLUX?

Are naval design, construction, strategy and all the rest of it in a state of flux? When Beatty led the German fleet into contact with the British, Jellicoe, with twenty-five battleships, had the speed and power to close in and absolutely annihilate the Germans. Why did he not do so? Because of his very proper fear of the torpedo. He escaped torpedo damage by keeping the German destroyers at such a distance that their torpedoes were discharged haphazardly, lost their speed before they reached the British line, and were easily avoided by maneuvering.

Have you ever considered that the gas engine is liable to upset many of the theories and practices of naval construction and warfare? It is a thought well worth consideration, and we invite attention to it just now.

Is it not rather strange that the British should have scrapped half their battleship fleet and stopped all battleship construction? And that they should so complacently sit down and watch another navy spending seven hundred and fifty million dollars on eighteen battleships and battle-cruis-

ers which, theoretically, when completed, will wrest from her that protective supremacy at sea which she has always believed, and still believes, to be necessary to the security of her far-flung empire? Why this complacency? If you asked Admiral Benson, he would probably answer, "They are hard up. It is necessity." But can we be so sure of this? Is it not possible that their vast war experience showed the British that the terrific punishing-power of the torpedo, due to new methods of bringing it within point-blank range of the enemy, demands a radical revision of some of our fundamental war concepts?

We believe that in future war the torpedo will at last come into its own, and it will be the internal combustion engine that will work the change. It gave us the motor car and the airplane, and now it is perhaps destined to dethrone the battleship and battle-cruiser as the supreme elements of naval strength. But how? Well, the British have several large and fast torpedo-plane carriers. Let us forecast a duel between a twelve-gun, 23-knot *Massachusetts*, and a 32-knot torpedo-plane carrier, with twice that number of planes aboard. Steaming outside of 16-inch gun range, the carrier would send in her planes which, swooping down from great height at 150 miles an hour, would drop their torpedoes within close range and return for more. But the bulge will save the ship? No; for the torpedoes will be set to pass underneath the ship and they will be fired magnetically by the action of the steel mass of the ship itself. And you could not put side and bottom bulges, both, upon a ship—she would be all bulge and but little ship.

Again, the internal combustion engine has opened up another form of attack in the shape of the so-called one-man torpedo boat—a type which is coming along very fast. It begins to look as though the gas-driven, high-speed, motor boat, carrying its torpedo discharge below water, would fulfill the functions in which the torpedo boat failed utterly and the destroyer partially. It has the torpedo efficiency of the destroyer without its size and visibility. To hit, the torpedo must be fired at close range—the Germans found that out at Jutland. The torpedo motor boat is so small a mark that it can dash in at thirty knots to within point-blank range without the anti-torpedo gunner being able to draw a bead upon it, so rapid is the change of range; and twenty-sea-going motor boats can be sent in for the cost of one destroyer.

Seaworthiness? Well, they are growing in size, and the latest type would have no difficulty in keeping station as part of a fleet organization.

There are evidences, clear to the close student of naval development, that naval theory, construction, strategy and tactics are very much in the flux just now or soon will be.—"Scientific American," August 14, 1920.

THE ERA OF THE EIGHTEEN-INCH GUN.

Although there is not as yet an 18-inch gun afloat in our Navy, there is reason to believe that already the adoption of the eighteen-inch gun is contemplated by the Bureau of Ordnance. If so, we shall probably have a renewal of the old controversy between the advocates of great volume as against great weight of fire, such as more than once has stirred up no little tempest on the calm waters of bureaucratic procedure and found an echo in the outside civilian world.

The contention that the discharge of a large volume of projectiles of moderate weight is more effective than that of a smaller number of much

greater weight and power, is as old as the history of the rifled gun. The question was hotly debated when we moved up from the twelve-inch to the fourteen-inch gun, and again when we discarded the fourteen-inch for the sixteen-inch gun; and it is certain that, if the tests of the new naval eighteen-inch gun should be satisfactory, the question will once more be threshed out along the old lines.

If the eighteen-inch gun should be adopted, it will probably be placed on some of our new 43,000-ton battleships. As designed, they were to carry twelve 50-caliber sixteen-inch guns, which means that on the same displacement and with the same speed, fuel supplies and general accommodations, they will be able to mount only eight eighteen-inch guns, particularly if the new pieces are to be of 50-caliber length. Many people will be surprised that a reduction of fifty per cent in the number of guns should be necessary when the caliber is increased only about twelve per cent, but this is because the weights of guns and projectiles increase approximately as the cube of the diameter. This applies not merely to the rifle itself, but it affects also the weight of the mount and the loading mechanism, the total weight of projectiles in the magazine, and so forth.

In favor of an eighteen-inch gun are the following points: The gun is more accurate; its range and energy are much greater; the bursting charge also is greatly increased, and therefore the destructive effect, when penetration of armor has been effected, is far greater.

The disadvantages are that not only is the number of shells delivered in a single salvo thirty per cent less for the eight-gun battery, but because of the greater weight both of gun and ammunition, the rate of fire is slowed down, so that the total number of projectiles delivered in a given time against the enemy is considerably over thirty per cent less than that delivered from the twelve-gun ship.

Now, bearing in mind the common saying aboard ship that it is the shells which hit that count, it can be seen that there is over a fifty per cent better chance of landing on the enemy with a twelve-gun *Indiana* than there would be with an eight-gun *Massachusetts*. The sixteen-inch shell weighs 2,100 pounds, and if we aim at the highest velocities and make our eighteen-inch gun fifty calibers in length, the weight of its projectile will probably be about 3,000 pounds, a fifty per cent increase in weight which must necessarily slow down the speed of handling. The only eighteen-inch gun afloat is the big fellow which the British built for the 32-knot cruiser *Furious*, but subsequently mounted on a monitor and used in the bombardment of Zeebrugge. With a view to extending the life of the gun, the British used a heavy projectile weighing 3,600 pounds and having a moderate velocity.

Despatches from Washington state that 18-inch guns are to be used on two of the new battle-cruisers. If so, one turret and a pair of guns would have to be dropped, leaving these ships with six eighteen-inch guns in two-gun turrets, which would be an arrangement similar to that on the battle-cruisers *Repulse* and *Renown*, which mount six fifteen-inch guns in three turrets.

If the eighteen-inch gun is to be adopted because of its superior range, it will be possible to utilize it at the longest ranges only in combination with airplane spotting and to make sure of spotting from a point above the enemy's ships, it is necessary that the attacking ship be accompanied by a fleet of fighting machines, sufficiently powerful to insure absolute superiority in the air.—"Scientific American," July 10, 1920.

MECHANICAL EFFICIENCY OF OIL ENGINES.

It is generally assumed that the mechanical efficiency of oil engines is in the region of 75 per cent. The late Mr. Knudsen, in his paper on "Performance on Service of the Motor-ship *Suecia*" ("Transactions of the Institution of Naval Architects," Vol. 55), said that the mechanical efficiency of Diesel engines of the type used in that vessel, but with the whole of the compression of the air necessary for fuel injection performed by the engines themselves instead of by auxiliaries, had been shown by bench trials to be 80 per cent. It should be possible by comparing the screw performances of oil engined ships with those fitted with reciprocating machinery to arrive at a close estimate of the relative mechanical efficiencies of the two types. Unfortunately very little data have been given regarding the trial and sea performances of oil-engined ships, and while estimated powers and revolutions may suffice to enable engineers to arrive at the dimensions they consider suitable the actual revolutions and power may vary very much from the estimated. Unfortunately also the particulars of the screws with accurate records of power and revolutions are very seldom available, at least, these are seldom published. The late Mr. Hall Brown gave an instance during the discussion on the above paper of the great improvement brought about in the performance of the oil-engined vessel *Eavestone* by an increase in the diameter of propeller and a reduction in number of revolutions. It is certain that the high number of revolutions of oil-engined ships leads to low screw efficiency, but a compensation seems to be obtained in the greater immersion of the screws. The voyage results of oil-engined vessels indicate a steadiness in running which is not a feature of the ordinary tramp. —"Shipbuilding and Shipping Record."

PROPELLER PROBLEMS.

Some years ago the late Sir Wm. White said that experience in ships of high speed and new types had given illustrations of a most remarkable nature of the economies or waste of power which may be involved in the use of suitable or unsuitable propellers. This experience is not limited to warships, but probably no class of vessel has given more striking illustrations of what may be done by changes and improvements in screw propellers than vessels of the torpedo flotilla. In these, great economies in power and large advances in speed have resulted from changes in the forms or areas of the blades of screw propellers. In ships of the cruiser class also notable examples of economy in power can be recorded. In the *Drake* class an alteration to the propeller blades raised the speed from 23 to 24 knots. The question naturally arises as to whether experimental investigation could guide to the propeller of greatest efficiency without the great expense accruing from actual trials with the full sized ship. It is certain that our knowledge of screw propellers and their action has been greatly increased since Sir Wm. White made the above remarks, but it is not certain that tank direction can indicate or point to the screw of greatest efficiency. It is well known, for example, that cavitation cannot be reproduced in tanks with model screws, and it is possible that many of the improvements referred to by Sir William were due to the adoption of more liberal blade area with a consequent reduction of thrust pressures and obviation of cavitation. No doubt a great deal in the way of general direction can be gained from existing experimental data, but experience is the great thing, and that does not always agree with experiment.—"Shipbuilding and Shipping Record."

JAPANESE NAVAL ESTIMATES.

Japanese naval estimates presented to the House of Representatives a few days ago provide for the construction of four Dreadnoughts, four battle-cruisers, twelve cruisers, and auxiliary vessels. In presenting the estimates, the Japanese Minister for the Navy said that the building capacity of the native yards was two capital ships a year. The naval programme was not, he added, directed against any potential enemy, but was dictated by the insular position of Japan, although the possibility of the dispatch of foreign naval strength to the Orient had not been disregarded. —"The Engineer," July 23, 1920.

SALE OF BRITISH DESTROYERS.

The Admiralty has this week decided to offer for sale no fewer than eighty-five destroyers. The vessels listed for sale include, it is stated, the *Lance*, which is believed to have fired the first shot in the war at sea, and the *Portia*, a comparatively modern ship. When these vessels have been sold none of the units remaining in British destroyer flotillas will be more than five years old. In other words, all those on the active list will have been constructed since the outbreak of war.—"The Engineer," July 6, 1920.

GEORGE MONTEFIORE ENDOWMENT.

Triennial Prize.

Article I.—A prize, the amount of which is the accumulated interest of a capital of 150,000 francs of Belgian funds at 3 per cent, is awarded every three years as a result of an international competition for the best original work presented on scientific advancement and on progress in the technical application of electricity in all fields, excluding works of popularization or of simple compilation.

Article II.—The prize bears the name of *George Montefiore Foundation.*

Article III.—Only the works presented during the three years that precede the meeting of the jury will be admitted to the competition. They must be written in French or English and may be printed or in manuscript. However, the manuscript must be typewritten and in any case the jury can decide on the printing.

Article IV.—The jury is composed of ten electrical engineers, five of whom are Belgians and five foreigners, under the presidency of the directing professor of the Montefiore Electrotechnical Institute who is by right one of the Belgian delegates.

With the exceptions stipulated by the founder, the latter cannot be chosen outside of the holders of the diploma of the Montefiore Electrotechnical Institute.

Article V.—By a majority of four-fifths in each of the two sections, foreign and national (who must to this end vote separately), the prize may be as an exception divided.

By the same majority the jury can grant a third of the available sum, at most, for an important discovery, to a person not having taken part in the competition or for a work which, while not coming completely within the scope of this plan, shows a new idea that may have important developments in the domain of electricity.

Article VI.—In case the prize is not awarded or if the jury only awards a partial prize, the entire sum thus made available will be added to the sum for the following triennial period.

Article VII.—The typewritten works may be signed or anonymous. Any work will be considered anonymous that is not provided with a legible signature and the full address of the author.

Anonymous works must bear a device, repeated on the outside of a sealed envelope with the enclosure; inside this envelope the name, first name, signature, and residence of the author must be legibly written.

Article VIII.—All works, whether printed or typewritten, are to be submitted in twelve copies; they must be addressed post-paid to the Secretary and Archivist of the George Montefiore Endowment, office of the Association, Rue Saint-Gilles, 31, Liége (Belgium).

The Secretary will acknowledge the receipt of contributions, to the authors or other senders who make themselves known.

Article IX.—The works which the jury decides to have printed will be published in the *Bulletin de l'Association des Ingénieurs électriciens sortis de l'Institut électrotechnique Montefiore.* In this publication there will be neither any expense to them nor any rights redounding to their profit. Nevertheless, as a compliment, twenty-five copies will be set aside for them.

For this publication the English texts can be translated into French at the expense of the Association.

COMPETITION OF 1917 EXTENDED, AS AN EXCEPTION, TO 1921.

The amount of the prize is twenty thousand francs.

The last date for the reception of works to be submitted to the jury is April 30, 1921.

The works presented must have clearly written at the top the heading: "Work submitted to the competition of the George Montefiore Endowment, session of 1917 (1921)."

BOOK REVIEWS.

MARINE ENGINEERS' HANDBOOK. Prepared by a staff of specialists. FRANK WARD STERLING, LIEUT. COMMANDER, U. S. N. (RET.), EDITOR-IN-CHIEF. McGRAW-HILL BOOK CO., INC., 239 WEST 39TH ST., NEW YORK CITY. 1458 pp. and index. Numerous illustrations. Tables. $7.00 net.

This is a new addition to the deservedly popular line of useful hand books for engineers and is the first one of its kind on this subject, being primarily for marine, but valuable to all engineers. It contains sections on mathematical tables and formulae, non-ferrous and ferrous metals, heat, fuels and combustion, marine boilers, turbines and reduction gears, reciprocating engines, marine Diesel engine, vacuum and condensers, ship forms and screw propellers, auxiliary machinery, pipes, valves and fittings, marine electrical installation, lubrication and lubricants, measuring horsepower of marine engines, and tests, trials and inspection of machinery. It contains much data obtained from the Bureau of Engineering, the U. S. Naval Engineering Experiment Station, the U. S. Naval Fuel Oil Testing Plant, and from articles published in this Journal. The specialists who furnished material for the various sections are well known practical men in their respective fields of engineering and their work is well co-ordinated in this book.

The volume is well and carefully prepared and it is believed will prove of value to the operating engineer and to the student, and to a slightly less degree to the designer.

NAVAL CONSULTING BOARD OF THE UNITED STATES, BY LLOYD N. SCOTT, FORMERLY CAPTAIN, U. S. A.; GOVERNMENT PRINTING OFFICE, WASHINGTON, D. C.

A treatise on the origin and organization of the Board, and its part in the industrial preparedness campaign; its considera-

tion of the fuel oil problem of the Navy; the special problems, such as listening devices, considered by it; the inventions or suggestions, meritorious and otherwise, submitted by the public; and the inventive accomplishments of its members. Some of the appendices with their accompanying charts are more interesting and instructive than the main body of the work.

MATHEMATICS FOR ENGINEERS. PART II. BY W. N. ROSE; E. P. DUTTON AND CO., NEW YORK. 419 pp. ill. 7.00 net.

This is the second volume of a work which is intended to give the mathematics necessary for engineers as differentiated from that necessary for students, or that given in practical books wherein formulae are given with no information as to the derivation of them. It covers, in so far as is possible in its scope, calculus, differential and integral, spherical trigonometry, and mathematical probability and least squares, and contains a number of practical problems.

BOY'S BOOK OF SEA FIGHTS. BY CHELSEA CURTIS FRASER; THOMAS Y. CROWELL COMPANY, NEW YORK. 333 pp. 28 ill.

This is a description of sea fights from the time of Sir Francis Drake to and including the World War, written in an interesting manner, as the title states, for boys, but also interesting to the older reader.

ASSOCIATION NOTES.

The regular meeting for the nomination of officers for the year 1921 and for other proper business was held at the Navy Department, Washington, D. C., on Tuesday, October 5, 1920. Nominations were made as follows:

For *President:*

Captain A. J. Hepburn, U. S. N.

For *Secretary-Treasurer:*

Commander J. S. Evans, U. S. N.

For *Member of Council:*

Rear Admiral B. C. Bryan, U. S. N.
Capt. (C. C.) Robert Stocker, U. S. N.
Commander F. J Cleary, U. S. N.
Commander S. C. Hooper, U. S. N.
Commander Kenneth Whiting, U. S. N.
Lt. Commander M. R. Daniels, U. S. C. G.

A meeting to count votes cast for officers will be held at the Navy Department, Washington, D. C., on Thursday, December 30, 1920, at 4:30 p.m.

An invitation to join the Federated Engineering Societies was referred to a committee to investigate the desirability of accepting the invitation, the matter to be placed before the membership if the committee so recommends.

The following committee was appointed to arrange for a dinner pursuant to vote of the Society at the beginning of the present year:

Commander F. J. Cleary, U. S. N.
Lt. Commander W. D. Chandler, U. S. N.
Lt. Commander John Q Walton, U. S. C. G.
Lt. Commander F. C. Sherman, U. S. N.
Commander H. A. Stuart, U. S. N.

At a meeting of the Council held on October 12, 1920, Lt. Commander M. R. Daniels, U. S. C. G., was appointed a Member of the Council of the Society for the remainder of the calendar year 1920, replacing Lt. Commander W. M. Prall, U. S. C. G., who has been detached from duty in the vicinity of Washington, D. C.

The Council also decided that it is necessary to increase the rate for advertising space in the JOURNAL of the Society, 25 per cent. This change will be effective with all contracts signed after December 31, 1920.

The Committee having in charge the dinner to be given by the Society has decided to hold the dinner on Saturday, December 18, 1920, at the New Willard Hotel, Washington, D. C. Announcement has been sent each active and associate member. The Committee would appreciate as early information as is practicable from those who find it possible to attend. It is anticipated that this will be a most enjoyable gathering.

The following members and associates have joined the Society since the publication of the last JOURNAL:

MEMBERS.

Simpson, E. P. A., Lt. Commander, U. S. N.

ASSOCIATES.

McClure, R. C., Lt. (T), U. S. N., Naval Fuel Station, Charleston, S. C.

Sherwood, Carlyle S., 4914 Third Avenue, Los Angeles, Calif.

Wilcos, J. Millick, Chile Exploration Co., Tocopilla, Chile.

The Secretary-Treasurer ventures again to remind members that only by prompt notification of each change in address can he be enabled to make sure that every one invariably gets the JOURNAL.